Rock and Overburden Piles

Review and Evaluation of Failures

Interim Report

March, 1992

British Columbia
Mine Waste
Rock Pile
Research
Committee

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DOCUMENTATION AND EVALUATION OF MINE DUMP FAILURES FOR MINES IN BRITISH COLUMBIA

Prepared for:

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This report was prepared for the Mine Waste Rock Pile Research Committee, and under the auspices of the B.C. Ministry of Energy, Mines and Petroleum Resources, contract number 91-114.

Canadian Cataloguing in Publication Data
Broughton, Scott E.
Documentation and evaluation of mine dump failures for mines in British Columbia

Added title on cover: Mined rock and overburden piles
On cover: Interim report.
Issued by the Ministry of Energy, Mines and Petroleum Resources
ISBN 0-7718-9182-2

1. Coal mines and mining - Waste disposal - British Columbia. 2. Coal mines and mining - Waste disposal - Environmental aspects - British Columbia. 3. Mineral industries - Waste disposal - British Columbia. 4. Mineral industries - Waste disposal - Environmental aspects - British Columbia. I. British Columbia. Ministry of Energy, Mines and Petroleum Resources. Resource Management Branch. II. British Columbia Mine Dump Committee. III. Title. IV. Title: Mined rock and overburden piles

TD899.M5B76 1992 622'.334 C92-092140-X

FOREWORD

Mine waste rock and overburden dumps are massive structures. Mountain top coal mines in British Columbia are constructing the largest man-made structures on the face of the earth. These immense waste dumps are often up to 400 meters high, contain in excess of one billion cubic meters of material, and often form mid-valley fills or rock drains. Instability of the structures has caused increased concern by mine operators and government regulators because of risk to the safety of personnel, equipment and infrastructure, and their impact on the environment.

In mid-1990 representatives of industry, CANMET, and the Ministries of Environment, and Energy, Mines and Petroleum Resources formed the Mine Waste Rock Pile Research Committee to foster research work and ensure a common understanding of these waste dumps.

The Interim Guidelines, published in May 1991, were the first two documents in a series undertaken by the committee. Three Interim Reports (Methods of Monitoring, Failure Runout Characteristics, Volumes I and II, and Review and Evaluation of Failures) continue the series of studies directed at improving our understanding of behaviour and developing a consistent database for waste dumps. Prominent geotechnical consultants and industry representatives have contributed their expertise to the studies.

The interim studies are being widely distributed by the Ministry of Energy, Mines And Petroleum Resources in the hope that all concerned with mine dumps will find them useful in establishing dumps that are stable, safe, and economically feasible. I anticipate that the studies will be distilled in the next year to develop a standard for investigation, design, operation, and monitoring of mine dumps.

In April 1992 the committee is sponsoring a series of workshops to introduce all of the studies to key industry personnel.

Tim Eaton, P.Eng.
Geotechnical Manager
Resource Management Branch

March 6, 1992

RESEARCH PROJECTS COMPLETED BY THE COMMITTEE

Investigation and Design Manual	(1991)
Operating and Monitoring Manual	(1991)
Methods of Monitoring	(1992)
Failure Runout Characteristics - Volumes I and II	(1992)
Review and Evaluation of Failures	(1992)

ACKNOWLEDGMENTS

The author would like to acknowledge both the technical and financial support for this project provided by Ministry of Energy, Mines and Petroleum Resources, Resource Management Branch. Mr. Ralph McGinn, Chief Inspector of Mines, has been a leading force in the advancement and application of technology for the mining industry by sponsoring studies such as this. The Waste Rock Pile Research Committee provided technical guidance for this report.

Mr. Richard Booth of the Fernie district office, and Mr. Dave Turner of the Prince George district office were most helpful by providing relevant information and assisting in the compilation of data.

The cooperation of the B.C. mining industry in the compilation of background information and site data was an important factor in producing a useful and relevant document. The author acknowledges the assistance of Byron Creek Collieries, Westar - Balmer Operation, Fording Coal, and Crows Nest Resources - Line Creek Mine.

The author would also like to acknowledge the important guidance and technical review provided by Prof. C.O. Brawner throughout this project.

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1.0 INTRODUCTION

1.1 Background

Mine dumps are used as heaps or pile sites to place barren and low grade rock which must be removed, or stripped, to access an orebody or coal seam. In this context, mine dumps have been referred to as tips, spoils, and spoil tips. Indeed 'spoil tip' is used as an universal term in many countries. The term 'waste dump' appears to have originated in North America and is common at metal mining operations, however, it is not always used at coal mines, where reference may still be made to 'spoil'.

With the increasing environmental concerns over special and hazardous waste materials, the use of words to describe these structures such as 'mined rock' and 'overburden piles' are becoming more common, to avoid the negative connotations perceived by the general public. The terms 'waste' and 'dump' are still in common usage at mine sites, and have a specific meaning to a mine operator. For the purpose of this report, since it is intended as a document for general distribution throughout the mining industry, the universal term 'dump' is used and refers to a mined rock or overburden pile.

While there is a long history of mining in British Columbia, mining methods and rates have increased tremendously in the past 20 to 30 years. Very large volumes of material are now being actively stripped and mined. This increase is due in part to the large scale mechanization available, and the resultant reduction in unit cost of mined material.

In addition, many deposits in mountainous terrain are only recently being mined in difficult topographic locations. Many of these orebodies were not developed in the past due to adverse conditions, and can now be mined due to improvements in mining technology and access to the orebody and site. The effect of mining at these sites is to produce larger volumes of overburden in more precarious locations than was traditionally encountered.

Mine dump failures around the world have been considered common events in the past (CANMET, 1970). In each case different, specific factors may have contributed to instability, however it is often reported that the cause could have been prevented or avoided during the design or construction of the dump. In general, failure can be attributed to the low level of effort expended during investigation, design, and construction phases. In many cases the level of effort in one or all of these areas has been minimal. The removal and handling of overburden material is a direct cost which affects the overall

profitability of the operation. It has been almost universally considered by mine operators that expending a high level of engineering effort on mine dump structures has no cost benefit.

In the past, failures of mine dumps were generally accepted as being a normal consequence of mining, or an 'act of God' as the general level of understanding was low. This changed dramatically after the 1966 Aberfan disaster in Wales. This failure of a relatively small spoil tip by modern standards, which failed due to high precipitation and high level of material saturation, flowed down from a hill side inundating a portion of the small town of Aberfan below. The debris struck an elementary school house where over 100 school children were killed. This event served as a catalyst to the mining industry to apply the technology for control of physical stability of embankments, which was traditionally a civil engineering practice. Bishop (1966) discusses the subsequent inquiry and geotechnical investigation into the spoil failure which caused the unnecessary deaths. There was also recognition that a study of the potential impact of failure, or risk assessment, needed to be made during the design and siting of these dumps. Investigations and reports on the Aberfan event served to influence the siting of future spoil pile locations, with special emphasis on failures which could impact directly on the public or third-party property. The recognition therefore developed that if a preliminary siting and assessment for a mine dump indicated the potential for large flow failure was high, and that critical structures existed downstream of the dump, then alternate sites or design controls should be investigated.

This design philosophy can be applied to British Columbia although, perhaps because of the relative remoteness of many of the mines in the province, failure of overburden piles have caused few incidents of fatality or property damage. One incident in southeastern British Columbia caused two fatalities of motorists when dump failure debris crossed a highway. Because of the current mine review process, few dump situations exist now in British Columbia where the public is directly exposed to a potential dump failure hazard.

In more recent years two principal concerns have arisen with respect to mine dump stability; safety concerns for mine workers and operating equipment on dump platforms, and the environmental impact of failure. The increasingly large volumes and rates of material placement will influence stability, and significantly increase the potential for failure which may cause fatality of mine workers and/or loss of equipment. Environmental consequences of failure have been primarily the downstream impacts on creeks and rivers due to sediment loading, and the subsequent loss of wildlife habitat. These types of

failures have resulted in modest fines to mine operators in some cases. The current focus for the management of mine dumps in the Province is primarily to ensure the safety of mine workers and to minimize environmental impact caused by failure. The former may be done by reducing the potential for failure or limiting the operational activity during periods of dump instability. This operating procedure is becoming a common alternative to ensuring stability, and is known as controlled failure.

Guidelines have been developed over the past twenty years for the design and construction/operation of mine dumps which are widely available (Mines Branch Mining Research Centre, 1972; MESA, 1975), National Coal Board [UK], 1970). However, many mines do not have the in-house resources to do the required design work and therefore use geotechnical consultants to provide dump designs and operating guidelines for specific mine sites. Consultants use a variety of tools and methods to create unique designs for the specific site. These designs universally imply stability of the structure under certain specific conditions and often describe circumstances where changes in the design or operation may impact on dump stability. This process is usually carried out away from the mine but in consultation with operators and regulatory authorities. Most mines have written in-house guidelines for the operation of dumps, focusing on the safety aspects for operating personnel during periods of deformation. However, few guidelines of this type exist for absolute failure prevention.

The dump design engineer is generally not present during construction (operation) of the dump and may only inspect the structure on an annual basis. However, site conditions and materials placed in the dump may change over time and vary considerably from the original design assumptions. Changes of conditions, especially material quality dramatically affect stability. Operators are essentially interested in the rapid and economical displacement of overburden from the mine to the dump, and are generally prepared to accommodate dump deformations and displacements. A subtle conflict arises as design and permitting is based on creating a stable structure. In practice, operators rely more on diligent monitoring to detect and react to deformations to protect the safety of the workers, rather than strictly conforming to the original geotechnical design.

Concerns with the potential environmental impacts and economic liabilities of dump failures for the industry prompted the B.C. Ministry of Energy, Mines and Petroleum Resources to develop, and publish documents outlining the current state of practice for design and monitoring of mine dumps for the control of physical stability.

1.2 Terms of Reference

It is evident that mine dump state-of-technology must be improved Province-wide if some measure of physical stability is to be maintained. In an attempt to meet this challenge the BC-MEMPR commissioned this study to review and document mine dump failures in the Province in a readily accessible database format. These records were evaluated to assess failure modes and probable causes for each event. The database was used to summarize mine dump failure trends including influencing factors and design/construction deficiencies. The document is presented as an interim report, with the intention that it will be used by the industry, refined and expanded as experience with mine dumps continues.

This study will compliment two other studies; Piteau and Associates Engineering Limited, 1991, "Interim Guidelines for Investigation and Design Manual", and Klohn Leonoff Ltd., 1991, "Interim Guidelines for Operating and Monitoring Manual", and is intended as a companion document to these manuals which are referenced throughout.

2.0 MINE DUMP FAILURE SUMMARY DATABASE

2.1 Dump Technology and Characteristics

A wide variety of mine dump types and characteristics exist in the Province of British Columbia. This is often a result of dramatic differences in site and material characteristics across the Province, including; site topography, climate, hydrology, the actual materials being placed, mining methods, and mining rates. The level of effort which goes into mine dump design and operation has also been extremely site dependent.

Operators of sites with favourable foundation conditions, suitable topography, competent waste rock materials, and relatively low loading rates (for example many metal mines), generally do not require substantial efforts to maintain or monitor the characteristically stable dumps.

Conversely, operators mining sedimentary sequences or highly altered orebodies in areas of poor foundation conditions and dramatic topographic relief are forced to expend a much larger effort in either maintaining stability and minimizing instability, or predicting failure based on monitoring. In addition, operators mining sedimentary sequences in British Columbia, generally coal producers, also mine and place overburden rock at a high rate. The loading rate of dump development has been documented as a specific cause of dump instability in many cases (Section 3). These factors make British Columbia's coal producers prime candidates for dump instability, and this is reflected in the failure record database and discussion of failure trends later in this document.

The database includes specific details for 44 mine dump failures in British Columbia which have occurred between 1966 to 1991. Each record of a failure is presented on a standard format sheet, with pertinent information specifically related to the failure. Mine dump failures over this time period that have been reported to the Ministry demonstrate varying degrees of completeness and levels of investigation, and indeed not all failures have been reported. The failure recorded database presented herein only includes failures which have been reported to the Ministry and which have a sufficient and accurate information base to be presented in the selected format. A bias for dump failure at coal operations is observed in the database records and is due to the factors controlling dump stability described above.

2.2 Database Records

The database records are presented in Appendix A and include several fact sheets for each failure record. The first sheet lists the salient technical characteristics regarding the dump in point and tabulated form. Within this format separate headings are established which provide details relevant to that section. The first section describes the fundamental physical dump and failure characteristics:

- the type of mine and mine designation,
- the dump designation;
- the date of the failure;
- the original height of the dump;
- the volume of the failed material (and any subsequent disruption of natural materials); and,
- the runout distance of the failed/disturbed material.

The second section is entitled General Data and reports site specific information such as:

- topography (slope angles and confinement);
- geometry and dump type;
- foundation conditions; and,
- method of construction.

The third section reports estimated or assumed quantitative values describing the material properties. These values were based on a combination of laboratory test work, *in situ* testing, and estimates based on experience of the designers, including back analysis of failures. These values were used to estimate the material strength and long-term behaviour of the dump.

The fourth section provides details of the dump design assumptions and the chosen method of stability analysis. The calculated factor of safety based on the method of analysis, the material properties, and the dump design is also presented. For each failure event record, this first sheet is a summary intended to provide sufficient information for a preliminary appraisal of the failure event.

The following pages present a brief discussion of the most likely failure scenario based on review of available records. This discussion is based on the authors' interpretation of the records pertaining to a specific failure event. Reported climate data (if applicable), loading rate data, and deformation data

(where available) are presented graphically. Some records include photographs of the post failure site. Photograph selection was based on availability, with preference given to photographs depicting the dump and setting, the failure surface, and the runout/disturbance.

2.3 General Data - Mine Dump Characteristics

The failure record database contains information on the investigated failures in a standardized format. Information required to make a critical assessment of specific failures is presented and includes actual or estimated values for each category. These values were reported in design reports, operating records, or failure reports. Details of each parameter found in the database is described in the following sections.

2.3.1 Topography (Foundation Slopes)

Topography plays an important, but not the only role in the dump geometry and therefore dump type, and has been observed to be of critical importance to dump stability. In the most fundamental analysis, steep slopes approaching the natural angle of repose for the overburden dump material are likely to exhibit ravelling, or other planar instability. Conversely, flat or near horizontal slopes may permit the development of a more stable 'stockpile' appearance. These concepts are understood by intuition, however the 'topography' of a site and its implications for dump stability is revealed in the three dimensional sense. This includes the overall configuration of the foundation slope; whether it is concave or convex in plan, and whether the shape in section is of importance.

Concave foundation slopes in section are similar to typical glacial U-shaped valleys where the slope angle gradually lessens to the valley bottom. Dump development on a concave slope often exhibits better stability characteristics due to the inherent stability of the toe material. While, conversely, dump development on foundation slopes which are convex in section generally exhibits some form of instability due to increasing slope angles at the lower portion of the dump.

Similarly, concave foundations in plan, such as gullies, often offer improved stability by virtue of material confinement, referred to technically as '3-D effects'. Convex foundations in plan which generally produce a topographic prominence provide poor foundation for mine dumps due to lack of confinement. Confinement is reduced in the convex case because of the coincident increase in lateral slopes, thus reducing stabilizing effects.

To evaluate these factors, the failure record database reports typical foundation slope angles for the length of the involved foundation divided into three parts; the *Crest slope*, the *Mid slope*, and the *Toe slope* respectively. These sections refer to the foundation slope angles observed over the height of the dump. Concave slopes in section will exhibit slope angle reductions down the slope, convex slopes will exhibit increasing slope angles, while linear slopes will have a constant slope angle. The failure record database also indicates the foundation shape in plan by stating the possibility of 3-D wedging effects; only concave foundation shapes in plan will provide this additional stability effect.

For the geotechnical engineer, the topography of a site offers insight into the geomorphologic and geologic evolution of the area. This includes contributing factors such as rock types, geologic structure, surface water and groundwater flows, and tectonic and glacial effects. The use of remote sensing techniques such as Air Photo Interpretation (API) to discern these factors, in conjunction with other site specific characteristics, can produce a wealth of geotechnical information and may allow an initial qualitative evaluation of material properties and strengths.

2.3.2 Geometry (Dump Types)

The method of dump construction provides the primary division of dump types:

- **Ascending construction** requires the development of lifts starting at the base of the structure and progressing to the ultimate height. Material is placed in a controlled manner in relatively small thicknesses (lifts). Once a lift is completed, the next lift is placed on top, and the sequence is continued until the ultimate or design dump height is reached. This controlled construction technique is commonly used in situations where sensitive foundation soils exist, and incremental loading allows these soils to drain and consolidate (strain harden) at rates suitable for foundation stability. Rapid loading of such soils may result in strain softening or static liquefaction (the occurrence of generated pore pressure trending to the overlying weight of material) which are discussed further in this report. Ascending construction is generally more expensive since it involves more material handling than other construction methodologies and construction monitoring is required. Monitoring of ascending construction should include the use of piezometers to evaluate the transient pore pressure regime in the foundation soils upon loading. The transient conditions include the excess pore pressures generated and the corresponding rate of pressure dissipation. In some instances, such as in deep valleys, ascending construction cannot be reasonably or economically carried out due the large haulage distances required to access the

valley from a mountainside orebody.

- **Descending construction** refers to the placement of material from the operating height and allows the dump to develop based on the natural material strength. Material is placed from the ultimate height, or crest of the dump. Typically material is end-dumped from the haul truck at this elevation. Variations on this procedure include the dump- short-and-push method, where trucks dump on the safety of the platform (without approaching a potentially unstable crest) and the material is then pushed by crawler dozer over the crest. The latter being a method enforced in many in-house mine guidelines for dumps which exceed a set level of crest deformation or height.

In general, assuming that no costs associated with the consequence of failure exist, the end-dumping method provides the most economical means of material placement for dump development. The method has lead to the development of some dumps in excess of 400 metres in height, for example, where coal seams are mined at mountaintop elevation and mine rock is placed in dumps developed in adjacent valleys.

In British Columbia, four common types of dumps are reported and are further described in Piteau (1991), they include;

- sidehill fill;
- valley fill;
- cross valley fill; and
- lift constructed.

Lift construction is the only ascending type construction method reported in the failure record database. A breakdown of the relative number of each type of dump is presented in the Design and Investigation Manual (MEMPR, 1991a), which provides the results of a Province wide survey of active and inactive mine dumps.

The failure record database reports dump type and the construction method, both of which are a reflection of the designer's concern for foundation response. If the construction method included thin lifts for a lift constructed or bench fill, then the design was probably attempting to consider and account for poor foundation conditions. Secondly, the dump type partially indicates the degree of confinement. Sidehill fill dumps have a linear or normal confinement, whereas valley fills may have additional stability due to 3-D effects. Valley fills and cross valley fills have additional characteristics that lead to design

considerations including the possibility of excess water pressure from runoff and foundation seepage since these hydrologic factors are directly influenced by the topographic valley feature itself.

A common development for descending dumps is the construction of wraparound dumps. These dumps include the use of secondary benches and are another means of descending construction, where rock is placed on the slope of an existing dump at a lower elevation than the dump platform (MEMPR, 1991a). This method is only possible by achieving access to the specified elevation, and is often carried out as mining progresses to lower elevation. The benefit of wraparound berms is a general increase in stability for the overall dump. The placement of material in a wraparound berm is analogous to placing a toe berm, effectively flattening the overall slope, increasing the shearing resistance of the mass, and lessening the shear stresses induced in the foundation materials.

2.3.3 Height

Dump height is an important characteristic for stability, mode and speed of failure, and potential runout distance. In general, dump height is predetermined by the mine site physiography and mining rate. Dump locations are selected primarily on their convenience to the active mining area and, depending on the size of the area or the depth of the valley, the ultimate toe of a dump is dictated by the volume of material to be placed. Many dump failures have occurred for dump heights less than 150 m (MEMPR 1991b), and yet stable dumps have been developed in excess of 200 m. Dump height is not a direct indicator of the likelihood of failure, but must be considered in context with other dump characteristics such as material properties, foundation conditions, and loading rate.

Dump height for lift constructed dumps is generally very low in comparison to end dumped structures. This is due in part to site topography, and the sensitivity of the foundation soils, and the size of the operations that use the respective methods.

2.3.4 Foundation Conditions

The characteristics of the foundation play an important role in the stability of the dump, especially for foundation related failure modes. These characteristics are controlled by the existing material, which may vary from saturated soil to competent bedrock. The former poses substantial stability problems and the latter presents few stability problems. Any combination of the two may exist over the broad area of the dump foundation.

Much of the Province has only a thin veneer of weak soil over bedrock, due to the wide scale glaciation effects where weaker soils and weathered rock were removed during repeated ice advances and retreats. After the last glaciers retreated, exposed fresh bedrock surfaces remained. Over the years since this last retreat, generally only very thin veneers of soil (some being glacial moraine, some derived from bedrock weathering, and some organic) cover the bedrock. This scenario is apparent for many dump sites in the Province, especially for mines situated in areas of steep topography.

Exceptions do, however, exist, and these include thick deposits of weak lacustrine soils deposited in glacial lakes, alluvial deposits of sand and gravel in natural sediment catch-basins such as valley bottoms, and organic deposits developed in bogs. In addition, areas or pockets of substantial thicknesses of glacial till may be present. Generally, the soils deposited in lacustrine settings can be characterized as being sensitive, often existing in a saturated state, and often pose the most significant geotechnical problems for dump development.

During the development of many dumps in steep terrain, the physical action of placing rock is sufficient to displace loose soils and expose bedrock. This may be emphasized in dumps which have several minor failures during development. The result of minor displacements may be the overall improvement of foundation conditions, in that the dump material comes into more intimate contact with strong bedrock.

Bedrock conditions may also present geotechnical problems. These problems are usually due to the orientation of discontinuities, or planes of weakness. If the orientation of bedding planes, for example, is conducive to sliding down dip, then dump loading may induce failure along these planes. Structural discontinuities such as joints, shears, and faults may also provide adverse situations in which planes of weakness are accentuated by material infilling, gouge, or slickenside surfaces. Features such as these should be assessed prior to dumping and have been reported in the database if they exist for a specific case.

The presence of water within the voids of a dump seriously affects the dumps stability depending on the quantity or elevation of the phreatic surface (limit of saturation). Inflows of water to a dump include precipitation, snow melt, surface runoff, and foundation seepage. Surface runoff is controlled to a large degree by the physiography of the site, however manmade diversion systems can be constructed to minimize this amount. Foundation seepage can occur in the form of groundwater springs which are often

controlled by the geologic structure. These flows may be difficult to detect in a dry summer, but can yield substantial amounts of water during wet periods or spring thaw. A certain lag time is generally observed as the groundwater supply gradually increases. The potential presence of groundwater springs needs to be investigated prior to dumping. It is not uncommon for these features to be located in gullies or creek beds where contact with the natural groundwater table can be expected. Because gullies are often defined by the presence of groundwater discharge points due to long-term erosion effects, dump configurations such as valley fills or cross valley fills will require an assessment of the drainage characteristics of the foundation and fill material, to prevent build up of water within the dump. In the worst case, the construction of underdump drains may be required to improve the foundation drainage characteristics.

The Investigation and Design Manual (MEMPR, 1991a) describes specific types of investigations and testing methods which should be carried out to assess foundation conditions.

2.3.5 Material Properties (Dump)

The dump material properties listed in the database provide an estimate of the strength of the material based on rock types, percentages of each type, the unconfined compressive strengths, weathering and slaking potential, and the respective particle sizes. The strength of the resulting combination of material is generally based on a comparison of similar rock types and their relative compressive strengths and gradation. This information may be found in published literature or other technical sources, specifically for large rockfill dam structures. There have been very few instances for British Columbia projects where rock samples have been directly tested using large triaxial or shear testing apparatus. This is due mostly to the very large size requirements and the availability of capable testing sites. Comparisons of strengths have been made with rock fills used on large civil structures such as rock fill dams, where the overall project cost and very high level of design effort and public trust justifies the cost of testing the material. However, mine dump rock includes all overburden particle sizes placed in a random manner, and not in a selective basis as is common on civil engineering projects.

In most cases, dump designers make an estimate of the mass material strength based on their assessment of the different percentages of rock types and their individual characteristics. The estimated strength for the dump material in specific cases is reported in the database. In British Columbia, a common estimate for sedimentary rocks of variable durability, or for altered or weathered igneous or metamorphic rocks,

has been an effective angle of friction (ϕ') of 37° with no cohesion. It has been shown through the construction of hundreds of mine dumps in the Province that this value provides a good estimate of the strength of coarse blasted rock of moderate compressive strength during the early years after placement. This strength may be reduced over time due to various factors causing degradation of the material, and due to reduced friction values under higher vertical loads.

Particle sizes or gradation of the various composite rock types in a dump may influence the performance of the structure. This may be exhibited in several ways and will be discussed further in this document. However, of primary importance is the percentage of fine particles (typically finer than the standard No.200 sieve) which may absorb water (especially clay minerals), settle and blind natural drainage paths within the base of dump, and may impart some degree of apparent cohesion causing oversteepening in localized areas. In general, the higher the percentage of fines, the poorer the overall stability of the dump.

The particle sizes reported in the database are intended as an overall estimate for all of the dump material. In reality, the mine geology may change dramatically from bench to bench, such that, for example, one week strong competent rocks are placed and the next weak altered rocks are placed on the platform and down the face. In this scenario the overall particle size may be correct for the mass, although in reality a zone of fine, weak, and perhaps saturated material now lies on the dump face. Further loading, even of competent material, may result in instability due to the presence of this weak plane.

An assessment of the long-term behaviour and strength can be made based on the durability of the material. Durability may be quantified by laboratory test procedures including the Slake Durability (SD) test (ASTM D4644-87), and the Los Angeles Abrasion (LA) test (ASTM C535-87). Materials with low durability will weather rapidly to finer particles in the natural dump environment due to exposure to atmospheric moisture, wetting and drying, freezing and thawing, and high particle to particle loads. Movement within the dump also degrades the material and results in a rounded rather than angular shaped rock, with a coincident reduction in friction angle for the material.

This degradation phenomena is generally a long-term characteristic causing reduction in overall strength and the generation of fines which are ultimately washed down to the foundation contact. The fines may settle here and blind the contact area. Blinding of the foundation contact may be a factor of dump

instability originating at, or along, the foundation, and is due in part because of the inability of the foundation to drain under loaded conditions. This is especially important during periods of high rainfall or spring thaw, as described earlier.

2.3.6 Construction Method

The construction method used is often dependant on the dump type and geometry. Generally in British Columbia dumps using descending construction simply end-dump or dump-short-and-push material over the platform. This method is the most economical from a placement perspective, but is prone to serious deformations and stability problems related to dumping rate, topography, and dump height.

Most operators of this type of dump make use of monitoring equipment to gauge the relative deformations or movements of the active platform. Movement limits have been arbitrarily set at some sites and modifications made depending on the site or dump experience. Often the modifications simply permit the increase of material placement rates in the most economical manner from an operations point of view. Movement limits dictate the level at which material should be dumped-short-and-pushed, or that the dump should be closed. Generally, dump closure limits have increased over the years as operators become more familiar with the deformation response of the material, however recent larger limits may influence the likelihood of a significant failure event. It is important to note that since the implementation of monitoring systems, specifically wire-line monitors, the risk to men and machinery of a catastrophic failure has been minimized. Other methods of monitoring include conventional daily or weekly surveys and high technology continual 24 hour per day survey equipment with remote telemetry and warning system capability.

New dump deformation monitoring techniques include the use of remote sensing satellite techniques. However, to date no examples of the application of this technology to mine dump monitoring exist in the Province.

2.4 Design Assumptions

The failure record database presents design assumptions in a summary form. These assumptions were used in conjunction with the specific dump design, including the geometry, height, and topographic characteristics of the site to assess the stability of the design. The two principal parameters of the assessment being the relevant material strengths, and the piezometric assumptions made for the analysis.

In many cases, consideration of foundation conditions, the dump type, geometry, and construction method influenced the method of stability calculation, and are therefore reported. The design factor of safety based on the anticipated mode or modes of failure is also presented.

2.4.1 Material Strengths

The assumed strength of the dump and foundation materials are presented. In the design of most dump cases the effective friction angles and cohesion for the foundation are estimated for relatively coarse granular material. In instances where the assumption that any of the materials are not of this nature, for example sensitive lacustrine clays, an undrained shear strength is assumed more appropriate. Strength values for dump material are based on estimated strengths since, as noted previously, few large scale tests have been carried out on the material. Undrained shear strength tests are more easily carried out on fine grained soils, and samples can be recovered during borehole investigations of the foundation. A variety of in situ tests may also be performed to evaluate the strength of fine grained soils.

The database presents a range of strengths used in situations where the foundation is composed of a variety of distinct material horizons or zones, and at which depths or location have been predetermined by subsurface investigations including test pits or boring (MEMPR, 1991a). The orientation or configuration of the various materials will also have implications for the method of stability calculation. Each failure record is presented with the assumed strengths of materials and foundation conditions as assumed in the design report for that dump. The failure record database indicates that very few dump designs include an evaluation of the potential decrease in material strength with dump height.

2.4.2 Piezometric Assumptions

Piezometric conditions of a dump and the foundation are of primary importance for the assessment of dump stability. In most cases the assumption is made that the large coarse dump material has sufficient permeability so as to render the dump an effectively drained structure. The accuracy of this assumption is rarely investigated and yet the presence of an elevated phreatic surface in a dump structure substantially reduces it's overall stability, as it does for any geotechnical structure.

It has been proposed in the literature that material placed using the conventional end-dumping technique will segregate and that coarser material will arrive at the toe/foundation contact thus enhancing the permeability. The term 'flow-through drain' as it applies to mine dumps appears to have evolved from

the application of this practise. End-dumping from large heights and the simultaneous (unwitting) construction of a flow-through drain to enhance permeability are apparently co-benefits of the most cost efficient dumping method. The long-term characteristics, including degradation and blinding effects, which may reduce the performance of this drain appear to have been neglected. Also the reliance on a phenomenon that cannot be quantified or planned requires careful consideration.

The percolation of rainwater and snow melt through the dump will carry existing fine particles towards the dump foundation level. The generation of fine particles over time within the dump by natural slaking, weathering, and high point to point loads, adds to the fine particle or sediment load. Ultimately these fines settle, and could cause the blinding of the foundation interface contact within the dump, severely reducing the capacity of the assumed drained structure. The presence of perched water levels may also be created as fine grained, poor quality material is placed in one area or elevation of the dump. This may lead to localized areas of deformation and instability.

It is very difficult to assess the possibility of long-term blinding due to fines. This is due to the impracticality of excavation, boring, or testpits through a dump to determine its occurrence. The probability of occurrence is high, and dependant on the materials and in dump water flows of a specific site. Therefore, in instances where the durability of the mined rock is known to be low, such as most coal mines, the possibility of blinding should be assessed and reasonable design precautions taken to prevent any negative effects.

One documented case of a dump failure occurred where a portion of the dump remained in place. Inspection of the foundation contact area of the stable portion revealed that indeed coarse material was present at the contact but that the deposition of a large volume of fine particles was effectively blinding the contact zone for a thickness of approximately 2 m (Brawner, 1986).

Record No. 42 however indicates that during a borehole drilling program through a dump that drill circulation water was lost, and that large voids were encountered at or near the foundation contact, indicating at least locally that very high permeability exists in that dump near the foundation. Therefore, mine dumps do not necessarily all exhibit similar characteristics which affect stability. The reasons for these differences are rarely reported and very seldom investigated.

2.4.3 Methods of Stability Calculation

The method of stability calculation for a dump design is dependant on the anticipated mode of failure. The potential mode or modes of failure given specific site conditions are often difficult to assess. In most cases the method of stability calculation is based on a generalized slip surface, which may be a plane, an arc, or a combination of both. These generalized analyses include the identification of the slip surface with the lowest determined factor of safety while treating the dump mass as a homogenous body. Conventional methods of analysis are described in (MEMPR, 1991a; Mesa 1975). In reality, the mode of failure may be caused by a phenomena or an occurrence outside the realm of simplified parameters assessed in the design. Additionally, for such heterogeneous and anisotropic structures, limit equilibrium methods of stability assessment may yield erroneous results due to their inability to link stress and strain related phenomenon.

Although many dumps in British Columbia are located in a potentially active seismic zone, most dumps have been designed for only static conditions. The influence of ground movements or accelerations has been underestimated in dump design. In reality however, few dump failures can be attributed to earthquake phenomena; this may, however, only be a function that large dumps have never been subject to large earthquakes in the Province. Blast induced vibrations and hydrodynamic shock could also cause or induce potential instability, and one failure has been attributed to this in the absence of any other reasonable explanation. The case involves a small rotational failure which was coincident with a very large cast-blast at a neighbouring coal mine (Record No.39).

2.5 Factors Affecting Dump Stability

2.5.1 Material Quality

The influence material quality has on dump performance has been well documented in the literature. Generally, poor quality material in this context refers to a high percentage of fine-grained material, often with high water content. The stability problems observed with this kind of material largely depend on the incidence of occurrence within the dump. In most cases, these problems are also functions of the end-dumped method of construction leading to the occurrence of fine-grained material in several different forms and consequences:

a) **Mass dumping** Leading to embankment rotation failures where the fine grained material behaves as a weak homogeneous mass. In the end-dumped dump state it is very sensitive to pore pressure increases caused by rapid loading, precipitation, and foundation seepage pressures (due in part because of the large capillarity propensity fine-grained materials exhibit).

b) **Face dumping** Causing the formation of a plane of weakness along the face, continued use of the dump, even for dumping of good quality material will be susceptible to failure along this plane.

c) **Crest Dumping** or rapid dumping of fine grained material on the crest may result in local oversteepening. This is due to the apparent cohesion imparted by an increase in moisture content. Oversteepening has been documented to have caused crest slopes in excess of 43°. The implications of this phenomena include overloading the dump face or toe, or Sliver type failure of the oversteepened section. Sliver failures can be very rapid, high velocity events. In addition, rapidly placed, poor quality material is also very susceptible to precipitation or runoff related instability especially in its loose state.

Fine-grained, poor quality material may be found at any mine, and may consist of overburden soils, weak sedimentary rocks, or highly sheared and altered metamorphic or igneous rocks. In the latter case, the zone of poor quality material may occur within a specific boundary, thus reducing the overall volume. At coal deposits however the presence of weak fine grained overburden rocks usually represent a substantial volume of the total mined rock, and assessments are required to determine the behaviour strength of the mixture of mined rock when placed. Some effort is generally required to place large volumes of poor quality rock in a method such as to avoid the occurrence of instability described above. Methods such as spreading the material over the top of the dump platform in a non-continuous horizontal lift may minimize these hazards. Other methods may include the establishment of a separate dumping area with better dump site conditions, dedicated to the storage of poor quality rock, or more rigorously engineered and controlled structures.

The problem of poor quality material is exacerbated by the addition of water in the form of runoff or direct precipitation. For most mines in British Columbia, with substantial amounts of precipitation this represents a significant problem. It is important therefore to minimize the impact of precipitation on the dump by measures such as diversion of surface runoff, and adequate foundation preparation to minimize seepage inflows. In addition, many mines (especially in the East Kooteneys) are forced to 'rehandle'

dump material as the coal seam and pit elevation lowers. The practise includes the excavation of dump material which may have existed in a dump for many years. During this time the loose material has been susceptible to degradation and weathering and an increase in moisture content. When the material is rehandled and dumped again at another site its quality will have been reduced significantly, thus the role of mine planning must be emphasized to reduce the potential amounts of 'man-made' poor quality rock.

In many cases of mine dump failure where the mode of failure was similar to the simplified analysis made for the stability analysis, a general overestimation of the material strength may be inferred. This is especially true for the long-term stability, where particle shape and strength may undergo significant reduction over time.

2.5.2 Loading Rate

The impact of loading rate on physical stability has also been well documented. The placement of loose blasted rock or soils in a manner which does not allow for sufficient time for the material to develop strength at reasonable density will experience significant settlement or deformation. This practice may be responsible for the large yielding toe failures observed in the database, where loose material is rapidly placed, deforms and settles above a rigid and inherently strong toe (passive) block. The rapid loading and increase in toe loading associated with slope and crest deformations overload the toe block, as described in the following section, Failure Modes.

On dumps which do not exhibit large deformation of the crest and face upon rapid loading of rock, typically dumps which are of low height, the rapid loading of natural foundation soils may cause the generation of foundation pore pressures which do not dissipate fast enough to match the dumping rate. In these cases pore pressure related failure modes occur, including localized liquefaction, and foundation rotation failures.

Associated with high loading rates are the high allowable deformation rates which have been recorded prior to many failure events. Many mines have set arbitrary deformation rates which have evolved over the years of operation to new limits. These are generally based on the allowable deformation of dump crests as recorded by wireline extensometer. The general methods and uses of monitoring are discussed further in this document, and in MEMPR 1991b. The measurement of these large deformations, and visual observations indicate that very large strains occur within the dump material with settlement of loose

of loose rock. These high strains associated with rapid loading and high monitoring limit criteria may be responsible for the development of shear planes (planes of reduced shear strength) within a dump and for the general reduction in shear strength as particles are crushed and rounded under point loading.

While the use of monitoring techniques has limited the number of sudden or unanticipated failures and has lead to the construction technique known as *controlled failure*, the cost associated with the loss of dump availability requires further scrutiny. For example, it may be a cost benefit to ensure dump stability by minimizing loading rate or increasing dump crest length of a specific dump. These costs can only be realized and appreciated by mine operators.

2.5.3 Topography

As previously discussed, topography has a direct influence on dump stability in several different ways. In British Columbia, mine dumps are often constructed on generally steep terrain, and some discussion on the design implications has been made in the published literature (Campbell 1978, 1981, 1986) (Claridge 1986). The problems encountered with mine dump stability on steep terrain may be due to the difficulty in achieving adequate dump density and therefore the maximum shear strength of the material.

Other topographic problems include slope regions with increasing slope angles in the vicinity of the toe or side flanks. These are known as unconfined conditions and may cause the dump material to continually deform or ravel down slope, instead of achieving adequate density and mass strength. Gullies and valleys are often promoted as being ideal locations for mine dumps, because of the confinement associated on the lateral slopes. The additional support offered by these sites should be evaluated, and care should be taken not to overestimate the benefit of the 3-D effect especially in conjunction with other features coincident with gullies and valleys such as depth and condition of natural soils, the location of streams, springs, and as a focus for surface runoff.

2.5.4 Piezometric Conditions

The influence of water contained in a dump is a well understood phenomenon, depending on the location of the limit of saturation, or phreatic surface, stability of an earth or rock structure can be substantially reduced. In general, mine dumps are often considered to be free draining structures, offering no or little opportunity for water to build up. This assumed characteristic of dumps remains essentially unproven,

especially for aging dumps with low particle durability and high fines generation rate. The impact of flows due to precipitation and runoff directly onto a dump need to be evaluated for any design. In addition, inflows from the foundation, due to drainage under construction loading, or due to discreet seepage points or springs should be evaluated and measures taken to minimize the effect of these inflows. Flows originating from the subsurface are unpredictable to a large extent due to the lag time required for recharge, but have been observed to be substantial during spring melt and periods of high precipitation. The construction of foundation improvement features such as surface drains, (not necessarily relying on material segregation) should be employed if uncertainties exist regarding the impact of seepage on the dump.

Surface diversions should be constructed in almost all cases to prevent the flow of runoff water directly on to a dump area. In addition, mine facility water should not be allowed to drain into a dump.

2.5.5 Snow/Ice

Given the climate of British Columbia, the capture of snow within mine dumps is a common occurrence. Snowfalls of appreciable amounts have often been simply dozed off the platform and pushed onto the dump face where the snow is compacted by loading of dump material. Capture of snow and compacted snow/ice zones cause two areas for concern.

a) The formation of a distinct and continuous layer forming a plane of weakness along an inclined surface which is parallel to the dump face, (and indicates the location of the dump face at the time of the snowfall). A continuous plane of weakness such as this could lead to rapid planar type failure, especially if weak toe conditions exist. Planar modes of failure are reported for many dumps as a secondary mode after the loss of support at the toe region.

b) The existence of a zone of contained snow, insulated by the dump material over the course of many years, causing additional flows by rapid melting when in contact with volumes of rain or seepage water percolating through the dump.

2.5.6 Foundation Conditions

Foundation conditions such as the presence of weak saturated soil or similar zones affect stability of a dump by allowing deformation of the toe material. These conditions may result in specific modes of failure related to the yielding toe mode of failure. Similar conditions may arise where material is placed

on previous failure debris. Debris often exhibits a much lower strength than in its original state due to changes in particle size, particle shape, and moisture content. Many examples are cited in the database where instability could have been experienced due to the presence of weak saturated debris which remained after a previous failure event. Some subsequent failure records indicate the potential for pore pressure generation of this debris when it was loaded rapidly.

Foundation conditions at the toe of many dumps may be influenced by the topographic location. Many dumps toe-in at a valley floor, where the foundation conditions may include saturated granular or lacustrine material not present in the upper slopes. As dump development progresses onto weakening foundation conditions the dump is likely to experience instability, potentially including the mass of material supported by the toe block. These types of conditions are also susceptible to rapid increases in foundation seepage pressures which may occur during periods of intense rain or spring melt.

Foundation soils are susceptible to freezing in many parts of the Province. The rapid development of a dump during late winter and spring may cause the dump toe to be constructed above frozen conditions, and may effectively insulate it from normal thawing in the spring. Subsequent groundwater recharge in late spring or early summer could cause the elevation of pore pressure beneath the frozen soil, and may be sufficient to induce failure in the toe region, or to promote basal sliding along much of the foundation contact.

2.6 Modes of Failure

Mine dumps have been observed to fail in several different modes, details of most of these modes of failure are offered by a number of geotechnical handbooks dealing specifically with embankment stability.

Other sources of information on mine dump - embankment modes of failure include the Investigation and Design Manual (MEMPR, 1991a). These descriptions also provide a summary of conventional two dimensional limit equilibrium analyses for each mode. Reservations about the use of limit equilibrium methods are presented later in this document.

The following summary of failure modes applies specifically to the failure modes observed in the failure record database. Analysis of the failure record trends has been carried out for the purpose of this report.

To simplify the identification of specific modes a letter code has been assigned for each failure mode. These codes are identified after the mode heading in each of the following sections, and are bracketed, for example yielding toe is defined by the letter code (YT). Other common modes of failure which were however, not observed in the database are not described in this document.

2.6.1 Yielding Toe (YT)

Yielding toe failures involve local instability of the dump toe which may originate because of a variety of factors. These include:

- weak foundation soils at the toe;
- steep foundation slopes in the toe area (unconfined);
- high foundation pore pressure.

Yielding toe failures often have been observed to lead to progressive failure of the entire dump. This subsequent or secondary mode of failure occurs in a manner consistent with conventional modes. It has been observed that secondary modes of failure are more probably related to failure along a plane of weakness, such as basal or planar modes. In the absence of a plane of weakness, rotational failure mode coincident with maximum shear stress of the embankment may occur.

Review of the failure record database indicates a significant number of yielding toe type failure events, followed by a secondary, and generally much larger volumetric event. The author proposes that this progressive mode of failure is essentially caused by a massive redistribution of load within the dump due to the rapid placement of material, coincident low density and therefore undeveloped strength. These interpretations have been based on two key sources of information.

- Discussion by Campbell (1986) in which he proposes the validity of the double wedge mechanism method of analysis for large mine dumps. The method includes the realization of an active wedge supported by a passive toe wedge. The method of analysis provides factors of safety which are often in excess of other conventional analyses, however the amount of variation, if any, is dependant on the dump geometry and strength characteristics, especially of the foundation. Verification of the model is based on a physical dump model in which a scale dump was constructed using horizontal bands to indicate deformation. Deformations are observed by the displacement of the horizonal bands. Another verification for the model is the observations made

on many mine dumps constructed in steep topography, where the overall face of a dump can be divided into two distinct section from the crest to the toe. The upper section, often occurring in the upper half to 2/3 of the dump face is characterized by a ravelling, generally unstable appearance. The remaining lower section is characterized as being stable and in good condition.

These observations reinforce the concept of an active wedge supported by a passive toe wedge, delimited by a change in face characteristic. The description for the upper material provided by Campbell is that it exists in an active Rankine state, and infers that the active wedge material is essentially impounded, much like a dam, by the passive toe wedge. These characteristics are based on the visual inspection of many deforming mine dumps, and are highlighted for the purpose of this discussion. The limit equilibrium - double wedge analysis method is discussed further in Section 4.3.2. Limitations of the Limit Equilibrium Method.

- Visual observation of some dump failures where sufficient record keeping exists, indicates that prior to failure significant crest and face deformations occurred. These deformations ultimately closed the operation of the dump because of monitoring limits established at the mines. It was observed in several instances that as the crest deformed (dropped) a coincident bulging on the face occurred. This bulging was generally limited to an elevation below which no bulging occurred. These observations of continued deformation were recorded for a number of days prior to ultimate 'failure'. Consistent with the concept of a passive toe wedge or toe block, the visual observations also indicate very little toe movement, although this has never been adequately recorded by survey. Failure of the entire dump is then observed to originate from the toe area, (often recorded as being an 'explosive event' by eye witnesses), and progressive failure of the remaining mass ensues.

The proposed mode of failure for these types of events must be yielding toe by definition, however the causative factors may not be consistent with those summarized by other sources. It is proposed that the mechanism of failure for this mode, under similar conditions described, includes the massive redistribution of load within the active block. The active block is in a low density state, often consisting of high volumes of rapidly end-dumped material. Because of this the material does not achieve maximum strength, and deforms accordingly, while being impounded by the passive toe block. Deformations of the crest and face accelerate over time, causing loads to be applied on the toe block. These loads are

increasing and termed 'redistribution of loads' as the dump face bulges increasingly outward toward the toe block. This new loading of the toe block causes significantly higher stresses and coincident pore pressure response to be encountered in the toe block foundation, in a much shorter interval than dump loading rates may induce. 'Equivalent' loading rates may be assessed given the relative amount of face bulging.

Rapid increase in foundation pore pressure without opportunity for pore pressure dissipation under these loading conditions may cause the conventional yielding toe failure to occur under this unconventional mechanism of deformation leading to failure.

In the absence of this conceptual mechanism, reviewers of failures have often cited strain induced pore pressure as a causative factor for the yielding toe failure mode. Strain induced pore pressure may or may not require the displacement of the toe block over the foundation material in measurable amounts, however, this has not been recorded due the difficulty of displacement measurement of the toe while material placement is ongoing.

Yielding toe failures may also be named 'toe failure' or 'toe spreading' failures.

2.6.2 Basal (Foundation Contact) (B)

Basal failure refers to the failure of the dump mass along a plane of weakness associated with the foundation contact zone. This may be similar to a planar or base translation failure if the foundation contact is of constant slope angle. Similarly, a basal failure may resemble a circular arc, or rotational failure if the foundation contact occurs in that geometry. Non-rotational characteristics are more commonly observed with this mode, especially when the failing mass behaves with a low velocity movement over undulating ground which does not resemble a circular section.

The traditional basal failure mode has included the translation of entire blocks of the embankment, and was generally assumed to be displaced along a relatively planar contact. In this discussion, the basal mode of failure includes any pseudo-rotational, non-rotational, or block translation displacement that occurs at the foundation contact and does not occur at significant depth within the foundation.

2.6.3 Rotational Embankment (Re)

The rotational embankment relates to failure of a portion of the dump mass along a circular or curved failure surface within the dump itself. This mode may occur due the weak homogenous nature of the dump material. The failure surface is defined by the zone of maximum shear stress, and does not involve the foundation material, or foundation contact. Other causes for this mode of failure may include infiltration or foundation seepage elevating dump material pore pressure.

2.6.4 Rotational Foundation (Rf)

Rotational foundation failures include the mass failure of the dump material and the foundation material. This does not necessarily include failure of the overall dump, but does require extension of the failure surface through the embankment and into the foundation material. Causes of rotational foundation failures include high foundation pore pressure and weak foundation soils. Pore pressure generation due to loading is a possible, and likely common, cause of this mode of failure.

2.6.5 Sliver Failure (S)

Sliver failures are primarily a function of material quality and loading rate. Poor quality fine grained dump material with a sufficient degree of moisture will behave as an apparently cohesive material, with a temporary strength in excess of normal dump material. This will cause oversteepening of the dump, specifically in the crest area. Some crest slopes have been recorded in excess of 43°. Slopes as steep as these can be developed unwittingly due to the nature of the material and a high loading rate. Once oversteepened the crest material may fail along the normal angle of repose dump face due a variety of causes, including high precipitation and continued dumping of material at a rapid loading rate.

2.6.6 Liquefaction/Translation (L/T)

Liquefaction of foundation soils or of a distinct soil horizon may result in the translation of the dump mass, or cause a progressive failure of the dump. This mode of failure is essentially restricted to low lying topographic sites with shallow foundation slopes. Typical site conditions for these sites in the Province include sensitive lacustrine valley floor sediments and relatively unconsolidated alluvial deposits. These kinds of site foundations may include the presence of discrete silt or sand stratum of a continuous nature where the generation of pore pressure within these contained zones would not dissipate readily. Rapid placement of dump material, even in a controlled construction scenario, may potentially cause the liquefaction of the silt or sand horizon, and in turn cause the translation of entire blocks of foundation

and dump material to move in the direction of maximum slope.

The phenomenon may also be induced by a seismic event although no such case has been documented in the Province over the recording period. In general, concern related to liquefaction translation of sensitive foundation soils should be focused on the construction loading rate. Dumps of this nature constructed in the Province have had intensive site investigation and monitoring programs relative to other dump construction although not relative to other types of construction outside of the mining industry. However, these programs have proven to be insufficient and ineffective to date at not only identifying the potential mode of failure but also of predicting failure.

Secondary liquefaction may occur when the failure of a dump causes rapid loading of natural sensitive soils in a valley bottom setting. The impact of the failure debris on these soils causes the generation of pore pressure in a localized area. The area of disturbance quickly enlarges as more failure debris arrives and continues loading adjacent sensitive soils. Often the area of disturbance will move along the path of steepest slope angle, causing it to form a flow like failure with potentially long runout distance (disturbance distance).

2.6.7 Planar (P)

The planar mode of failure occurs due to a discreet plane of weakness within the dump material. This plane may include the presence of contained snow and ice, or a plane of weak poor quality material dumped on the embankment face.

Planes of weakness may also develop in dumps with high allowable strain rates causing the formation of shear planes, characterized by reduced shear strength, within the dump. This can occur where arbitrary deformation limits are set higher than the internal strength character of the dump can tolerate. As the deformation rate increases internal momentum can lead to a failure event with very rapid movement.

3.0 FAILURE RECORD TRENDS

Analysis of the failure record database has provided the basis for the following discussion on trends of failure, including the frequency and volume distribution for modes of failure (both primary and secondary). A review of the failure causes cited in each record provides the basis for a discussion of the frequency distribution for indicated causative factors of dump failure throughout the Province.

3.1 Indicated Modes of Failure

The database indicates many failures have occurred in a common or conventional mode. These modes are generally well understood and an appropriate back analysis can be carried out to assess actual average strengths or pore pressures within the dump. This type of single mode failure represents approximately 43 percent of the failures recorded in the database. The remaining failure records include multi-mode events, where the failure of a portion of the dump (generally the toe block) causes a loss of support for material above, consequently causing a secondary mode of failure which is different than the primary. Secondary modes of failure often occur along a plane of weakness in a planar or basal fashion, or along the zone of maximum shear stress in a rotational manner. In many cases, these two events occur so rapidly that the observer would not differentiate between two separate modes.

Review of the failure record database provides insight into the most common modes of failure observed in the Province. A comparison between the frequency of specific event types and the total volume associated with this indicates a wide range of scatter. This scatter is evident within failure mode types, but also highlights the volumetric range of some modes. For example, sliver failures are common, low volume events, and this is reflected in the database. Conversely, yielding toe failures have a much higher percentage of the total volume attributed to them than their frequency of occurrence might suggest.

3.1.1 Ungrouped Data Summary

The initial results of a statistical review of the database are presented on Table 1. Table 1 summarizes and places in order the relative significance of failure of the ungrouped data modes, both primary and secondary, according to the frequency of occurrence. In addition, the total volume associated with a specific mode is also indicated. The frequency and volume percentages for ungrouped data are based on the total number of failures recorded in the database and the associated volume.

The ungrouped data summary indicates that the percentage of primary and associated secondary failure modes has significant variations in the mode frequency and accompanying volume. The following discussion pertains to the most significant event modes.

- Yielding toe/basal (YT/b) events account for an 11.4 % frequency of occurrence, making it one of the four most common modes to be discussed. The volumetric equivalent for this combination of modes is 52.1 %. Thus, significant disparity exists between the frequency of occurrence and the volumetric percentage. While this characteristic of the mode is well defined, yielding toe failures with secondary basal modes are large volume events and therefore indicative of the mode. A single event displaying this mode however induces substantial bias into the analysis. Record number 10 is a failure of this type with a corresponding volume of 30×10^6 m^3. This one event accounts for approximately 40 % of the total database failure volume.
- Yielding toe/planar (YT/p) events account for 9.1 % of the frequency of occurrence, and yet have a relatively low portion of the total volume associated (4.2 %).
- Yielding toe/rotational embankment (YT/re) events have a low frequency of occurrence (6.8 %) and yet account for 7.9 % of the total volume, making this combination of modes the second largest volumetric failure type.
- Basal (B) events account for 11.4 % of the frequency of occurrence, but as a single mode of failure it represents only 3.2 % of the total volume.
- Rotational embankment (Re) events make up the most frequent events with 13.6 % of the total, however this mode is associated with only 4.4 % of the total volume.
- Rotational foundation/planar (Rf/p) are the third highest volumetric events (7.0 %), with only 6.8 % of the frequency of occurrence.

The remaining failure modes and combination of primary and secondary modes are less significant, and are presented with the above data on Table 1. Further analysis of each mode is carried out in section 3.1.2 Grouped Data. This information is also displayed comparatively on Figure 1 in the form of a bar chart indicating frequency and volume percentage based on the totals of each. To further analyze the trends of the database, the ungrouped data is presented in primary mode format and secondary mode format only on Table 2 and Table 3 respectively.

Failure Summary – Ungrouped Data – All Modes				
Primary Mode	Secondary Mode	Letter Code PRIMARY/secondary	Frequency (%)	Volume (%)
Yielding Toe	Basal	YT/b	11.4	52.1
	Planar	YT/p	9.1	4.2
	Rotation(e)	YT/re	6.8	7.9
	Liquefaction	YT/l	2.3	2.6
Basal (Foundation Contact)	(n/a)	B	11.4	3.2
	Rotation(e)	B/re	6.8	5.3
	Planar	B/p	2.3	5.3
Rotational (Embankment)(e)	(n/a)	Re	13.6	4.4
	Planar	Re/p	2.3	0.5
Rotational (Foundation)(f)	(n/a)	Rf	2.3	0.3
	Planar	Rf/p	6.8	7.0
	Rotational(e)	Rf/re	2.3	0.5
Sliver	(n/a)	S	2.3	0.6
	Planar	S/p	4.5	1.2
	Liquefaction	S/l	4.5	0.6
Liquefaction/Translation	(n/a)	L/T	6.8	3.9
Planar	(n/a)	P	4.5	0.4
Total Number of Failure Events			44	
Total Volume of all Failure Events				7.60E+07 m^3

Table 1

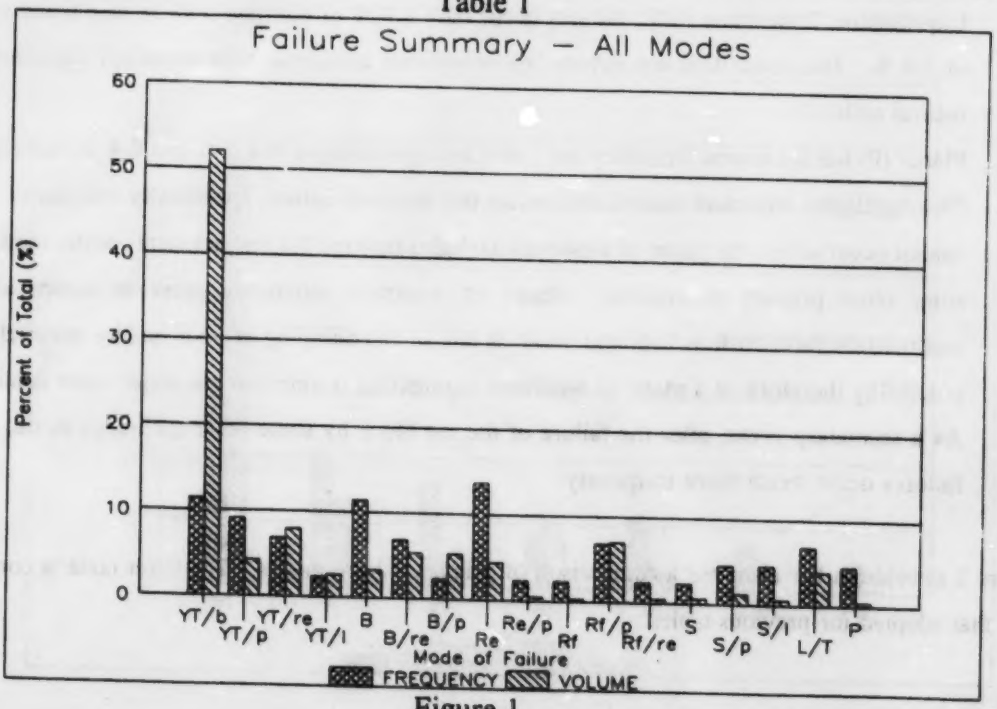

Figure 1

Primary Mode Analysis

The primary mode analysis displays the following results in order of frequency of occurrence. This analysis includes all failure modes for which there is no secondary event, and all primary modes for combination events.

- Yielding toe (YT) failure as a primary mode represents a total of 29.5 % of the total primary modes and a very large 66.8 % of the volumetric percentage. One event represents a disproportionate volume within this analysis.
- Basal (B) failure mode has a frequency of occurrence of 20.5 % and the second highest volumetric total of 13.7 %, based on the primary mode analysis.
- Rotational embankment (Re) failures occur 15.9 % of the time in the database with an associated volume of 5.0 %.
- Rotational foundation (Rf) failures occur 11.4 % with an associated volume of 7.8 % of the total.
- Sliver (S) failures occur 11.4 %, however due to the much smaller volume of failure associated with this mode, the percentage of the volumetric total is only 2.4 %.
- Liquefaction/Translation (L/T) failures occur only 6.8 % of the time with an associated volume of 3.9 %. This value does not include failure volumes associated with secondary liquefaction of natural soils.
- Planar (P) has the lowest frequency and volumetric percentages of 4.5 % and 0.4 % respectively. This highlights important factors concerning this mode of failure, specifically that planar events cannot occur unless the plane of weakness daylights through the embankment, or the toe fails by some other primary mechanism. Planes of weakness commonly occur in dumps along a construction face, such as captured snow or ice, or the dumping of poor quality material. The possibility therefore of a plane of weakness daylighting is very remote under these conditions. As a secondary event, after the failure of the toe block by some other (primary) mode, planar failures occur much more frequently.

Figure 2 provides a bar chart for a comparison of primary failure modes. The letter code is consistent with that adopted for previous tables.

Primary Modes of Failure – Ungrouped Data			
Mode	Letter Code	Frequency (%)	Volume (%)
Yielding Toe	YT	29.5	66.8
Basal (Foundation Contact)	B	20.5	13.7
Rotational (Embankment)	Re	15.9	5.0
Rotational (Foundation)	Rf	11.4	7.8
Sliver	S	11.4	2.4
Liquefaction/Translation	L/T	6.8	3.9
Planar	P	4.5	0.4
Total Number of Failure Events		44	
Total Volume of all Failure Events			7.60E+07 m^3

Table 2

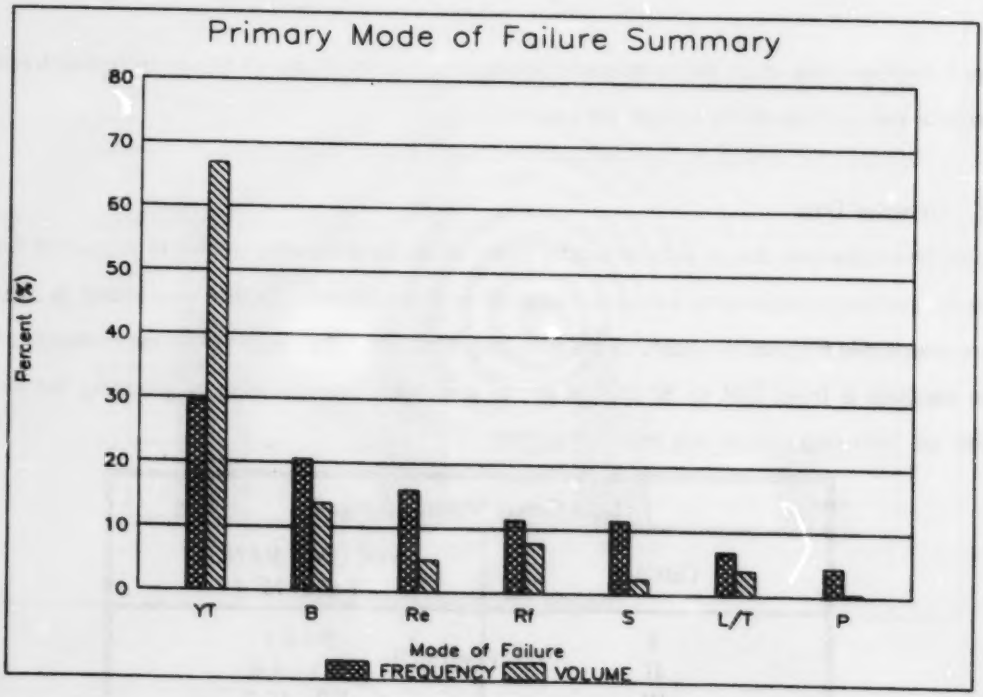

Figure 2

Secondary Mode Analysis

The secondary mode analysis reveals four types of secondary failure. These are ranked according to the frequency of occurrence on Table 3.

- Planar (P) mode of secondary failure represents 42.3 % of the secondary failure events and 20.8 % of the volumetric total. The frequency of the planar mode as a secondary event is consistent with the mechanism required for the mode, specifically the loss of support provided by the toe block.
- Basal (B) mode of secondary failure represents only 19.2 % of the frequency of occurrence and yet has 59.7 % of the total volume. This value is high due to the error of data scatter. Record number 10 (volume = 30×10^6 m^3) is included in the total volume calculation and represents 48 % of the total volume of failure associated with secondary modes.
- Rotational embankment (Re) mode of secondary failure occurs 26.9 %, associated with only 15.8 % of the total secondary mode volume.
- Subsequent liquefaction (l) of natural soils below a dump has occurred 11.6 % of the time associated with 3.7 % of the total secondary volume.

Figure 3 displays a bar chart for comparison between secondary modes of failure including frequency of occurrence and percent of the volumetric total.

3.1.2 Grouped Data

It should be emphasised that significant scatter exists in the database with respect to volume of failure and that some system is required to compare events of similar volumes. In this way scatter is reduced and a more reasonable frequency-volume correlation may be made. The range in volume estimates of failures in the database is from 0.01 to 30 million m^3, as a means of categorizing or grouping the failures by volume the following system has been developed:

Data Group Volume Ranges	
GROUP	VOLUME RANGE [$x10^6$ M^3]
I	0 - 0.1
II	0.1 - 1.0
III	1.0 - 10.0
IV	10.0 - 100.0

Secondary Modes of Failure – Ungrouped Data			
Mode	Letter Code	Frequency (%)	Volume (%)
Planar	P	42.3	20.8
Basal (Foundation Contact)	B	19.2	59.7
Rotational (Embankment)	Re	26.9	15.8
Subsequent Liquefaction (of natural soils)	I	11.6	3.7
Total Number of Secondary Failure Events		26	
Total Volume of all Failure Events with Secondary Modes			6.23E+07 m^3

Table 3

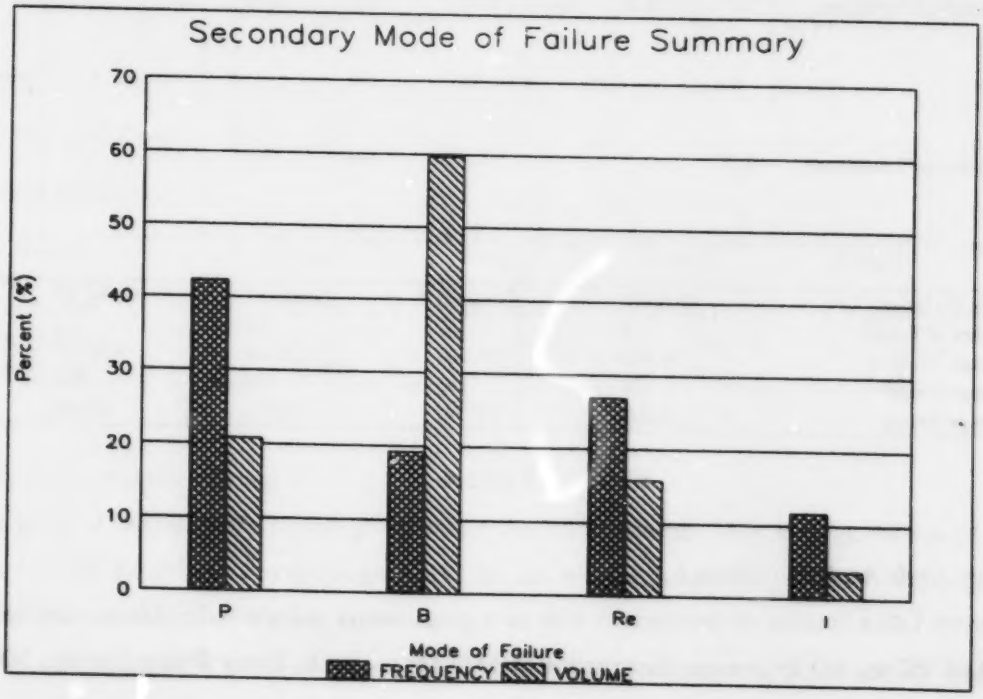

Figure 3

Data grouping in this pseudo-logarithmic manner allows further analysis and conclusions to be drawn by reducing the scatter of the whole database into groups of similar volume. The conclusions discussed however apply only to that specific group-volume, and cannot be applied outside of the volume range. The grouped data are summarized on Table 4 and 5, and are plotted for comparison on bar charts in Figures 4 through 7. In a similar manner to the ungrouped data analysis, the grouped data is discussed with reference to primary and secondary failure modes.

Primary Modes of Failure - Grouped Data

Mode	Letter Code	Group I		Group II		Group III		Group IV	
		Freq.(%)	Vol.(%)	Freq.(%)	Vol.(%)	Freq.(%)	Vol.(%)	Freq.(%)	Vol.(%)
Yielding Toe	YT	40.0	36.0	22.0	24.0	36.0	52.0	100.0	100.0
Basal (Foundation Contact)	B	-	-	26.0	38.0	18.0	19.0	-	-
Rotational (Embankment)	Re	20.0	34.0	15.0	8.0	18.0	8.0	-	-
Rotational (Foundation)	Rf	20.0	15.0	7.0	6.0	18.0	15.0	-	-
Sliver	S	-	-	19.0	18.0	-	-	-	-
Liquefaction/Translation	L/T	-	-	7.0	5.0	9.0	6.0	-	-
Planar	P	20.0	15.0	4.0	2.0	-	-	-	-

Group Statistics	Group I	Group II	Group III	Group IV
Number of Events	5	27	11	1
Average Volume	76,000 m^3	396,000 m^3	3.2E+06 m^3	3.0E+07 m^3
Average Height	152 m	182 m	232 m	300 m
Average Rating	[1330]	[1274]	[1272]	[1300]

Table 4

Primary Mode Analysis - Group I

The group I data consists of five records with an average failure volume of 76,000 m^3, average dump height of 152 m, and an average dump rating of 1330 (Appendix B, Dump Rating Scheme, MEMPR, 1991a). Four modes of failure were observed in this group are ranked by the frequency of occurrence, and include:

- Yielding toe (YT) mode of failure has a frequency of occurrence of 40 % and a volumetric percentage of 36 %.

- Rotational embankment (Re) mode of failure has a frequency of 20 % (1 record), however it has a disproportionate large percentage of the volume at 34 %.
- The remaining modes, Rotational foundation (Rf) and Planar (P), each have 20 % occurrence (1 record each) and 15 % of the total volume each.

Secondary Mode Analysis - Group I

The secondary mode statistics for group I include 3 records in this volume range with an average failure volume of 60,000 m^3, an average height of 145 m, and an average dump rating of 1253. Secondary modes for group I volumes include Planar (P) and Basal (B) failure modes with 66.7 % (2 records) and 33.3 % (1 record) respectively. Secondary planar failures are far more voluminous than basal mode failure, the volume percentages of the total for both are 94.5 % and 5.5 % respectively.

Secondary Modes of Failure - Grouped Data

Mode	Letter Code	Group I		Group II		Group III		Group IV	
		Freq.(%)	Vol.(%)	Freq.(%)	Vol.(%)	Freq.(%)	Vol.(%)	Freq.(%)	Vol.(%)
Planar	P	66.7	94.5	35.7	30.3	50.0	39.3	-	-
Rotational (Embankment)	Re	-	-	14.3	25.1	12.5	26.8	-	-
Basal (Foundation Contact)	B	33.3	5.5	35.7	36.7	25.0	27.2	100.0	100.0
Subsequent Liquefaction	l	-	-	14.3	7.8	12.5	6.7	-	-

Group Statistics	Group I	Group II	Group III	Group IV
Number of Events	3	14	8	1
Average Volume	60,000 m^3	440,000 m^3	3.7E+06 m^3	3.0E+07 m^3
Average Height	145 m	209 m	263 m	300 m
Average Rating	[1253]	[1368]	[1306]	[1300]

Table 5

Primary Mode Analysis - Group II

Failure group II represents the largest group with a total of 27 records. The average volume of group II failure is 396,000 m^3, the average height is 182 m, and average dump rating of 1274. All previously defined failure modes occur in group II, including;

- Yielding toe (YT) mode of failure has a frequency of occurrence of 22 % and an associated volume percentage of 24 %.
- Basal (B) mode has a frequency of occurrence of 26 % and a disproportionately large associated volume of 38 %. Within this grouping this is indicative that basal type failures are larger events than other respective modes.

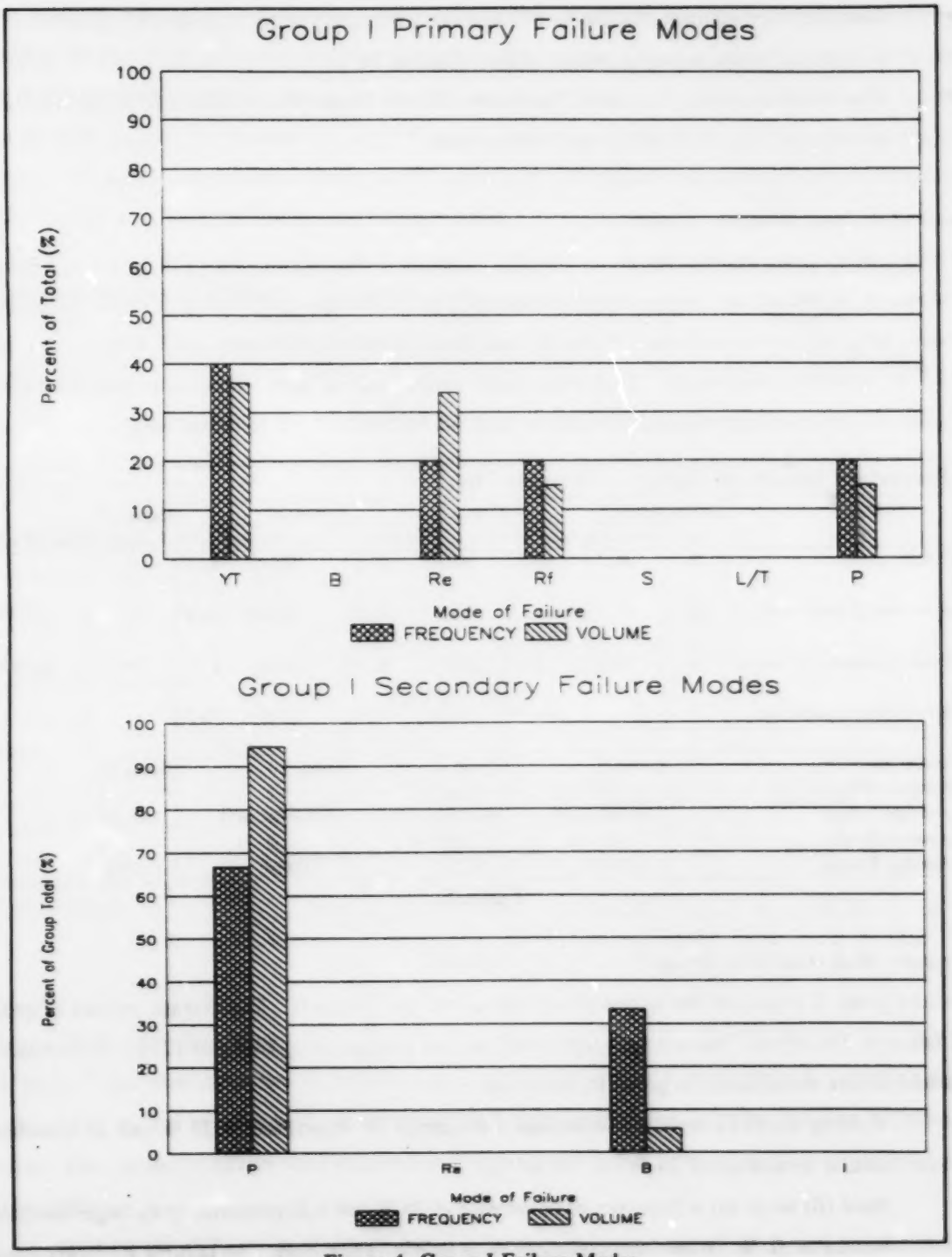

Figure 4. Group I Failure Modes

- Rotational embankment (Re) has a frequency of 15 % and an associated volume of 8 %.
- Sliver (S) mode of failure has a frequency of 19 % and a percentage of the total volume of 18 %.
- The remaining failure modes, Rotational foundation (Rf), Liquefaction/Translation (L/T), and Planar (P) range from 4.0 to 7.0 % in frequency and 2.0 to 6.0 % in total volume.

Secondary Mode Analysis - Group II

Group II secondary failures include all secondary modes previously described. The group statistics include an average failure volume of 440,000 m^3, an average dump height of 209 m, and an average dump rating of 1368. The secondary modes of failure and their associated frequency of occurrence and percentage of the total volume are as follows:

- Planar (p) mode of failure has a frequency of 35.7 % and a volume percentage of 30.3 %.
- Rotational embankment (re) mode indicates a frequency of 14.3 % and a disproportionately large 25.1 % of the total failure volume. It is apparent that as a secondary mode rotational embankment failures account for significant volume.
- Basal (b) mode accounts for 35.7 % of the secondary frequency and 36.7 % of the volume.
- Subsequent liquefaction of natural soils (l) occurs 14.3 % of the time however it only accounts for 7.8 % of the total secondary volume.

Primary Mode Analysis - Group III

Group III statistics include a total of 11 records with an average failure volume of 3,200,000 m^3, an average height of 232 m, and an average dump rating of 1272. The following modes of failure are observed within this group;

- Yielding toe (YT) is very prevalent within this group with a frequency of occurrence of 36 % and 52 % of the total volume. This disproportion between the frequency and the volume reinforce the conclusion that yielding toe type failure are large events.
- Basal (B) failure mode has a frequency of occurrence of 18 % and an associated volume of 19 %.
- Rotational embankment (Re) failures have a frequency of 18 % and a percentage of the volume of only 8 %, highlighting the fact that the recorded rotational embankment failures which occur as primary modes are relatively lessor events.
- Rotational foundation (Rf) failures have a frequency of 18 %, and an associated volume of 15 %.
- Liquefaction/Translation (L/T) have a low frequency of 9.0 % and an associated volume of 6.0 %.

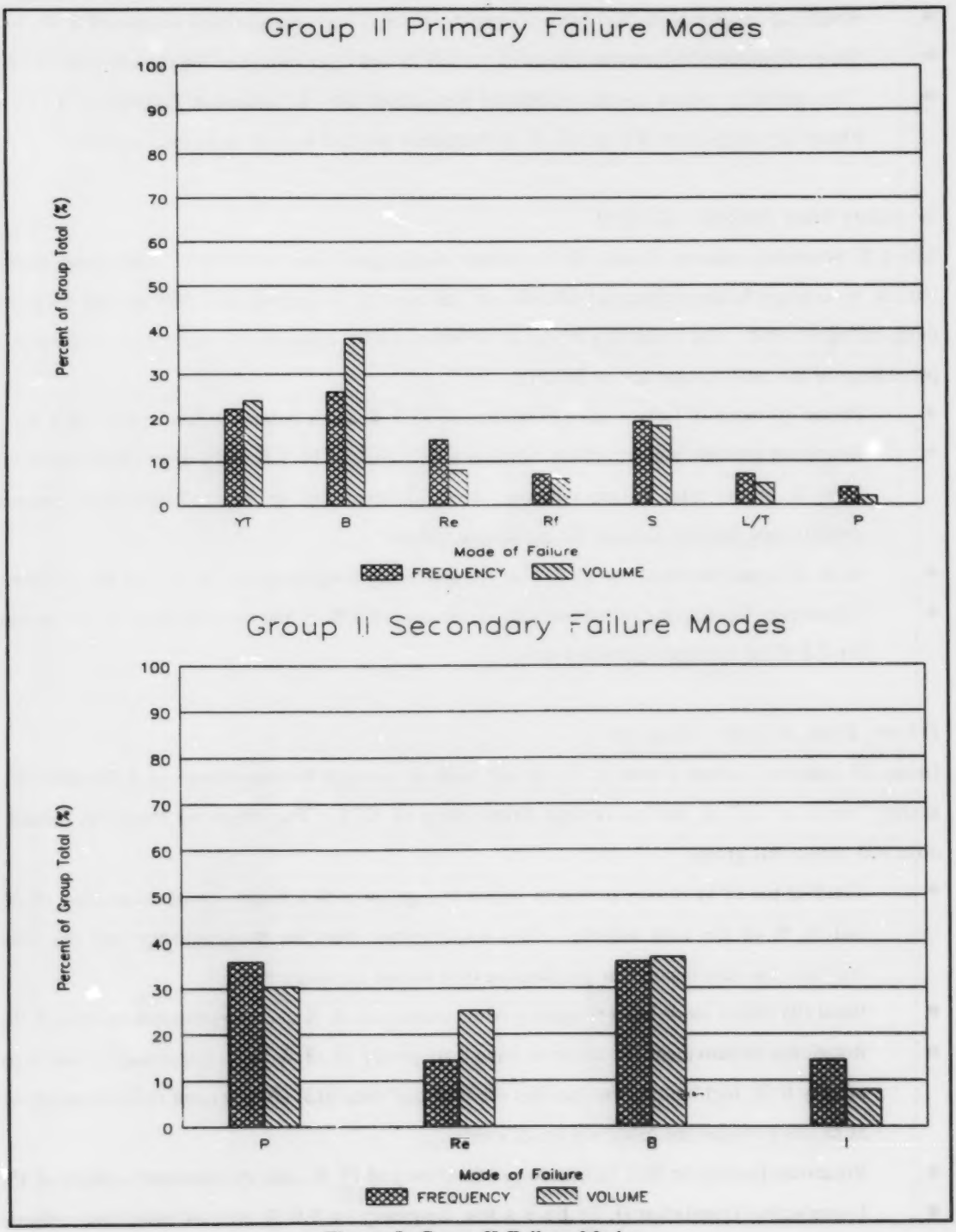

Figure 5. Group II Failure Modes

Secondary Mode Analysis - Group III

The group three secondary mode includes 8 records with an average 3,700,000 m^3, an average dump height of 263 m, and an average rating of 1306. The secondary failure modes associated with this group include all of the previously described modes. Most of these secondary modes are associated with the large frequency and volume recorded for the primary yielding toe mode.

- Planar (P) mode of failure accounts for 50 % of the frequency and 39.5 % of the total volume, consistent with this mode being a preferred secondary mode after loss of toe support.
- Rotational embankment (Re) mode of failure has a frequency of occurrence of 12.5 % and a percentage of the total volume of 26.8 %. This disproportionate volumetric percentage is consistent with the group II secondary rotational embankment mode.
- Subsequent liquefaction of natural soils (l) is recorded 12.5 % of the time with an associated volume of 6.7 %.

Primary Mode Analysis - Group IV

Group IV range includes such large volumes as to be outside the range of 98 percent of the failure records, however it is significant that this largest event has a primary failure mode consistent with the most common mode of failure for the database. In reporting the statistics for this group it should be recognized that this represents only one record, and that the averaged values therefore are that of the one record. The volume of the failure was estimated to be 30,000,000 m^3, with a height of 300 m and a dump rating of 1300.

- Yielding toe (YT) was the primary failure mode for this dump and therefore accounts for all of the occurrences and volume.

Secondary Mode Analysis - Group IV

Similar to the statistics reported for the primary mode, one record accounts for all of the group, therefore volume, dump height, and rating are the same.

- Basal (B) failure was the secondary failure mode after loss of support.

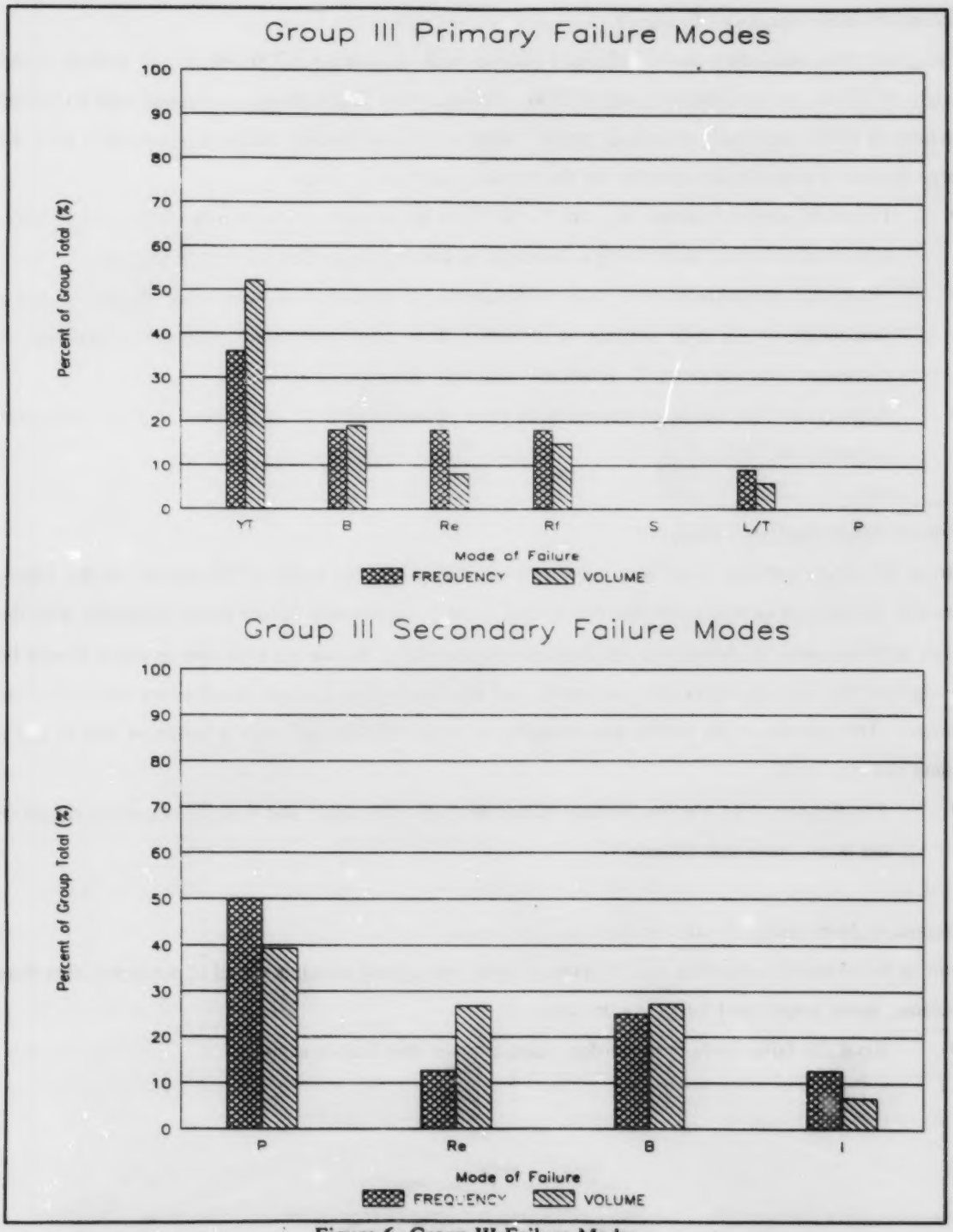

Figure 6. Group III Failure Modes

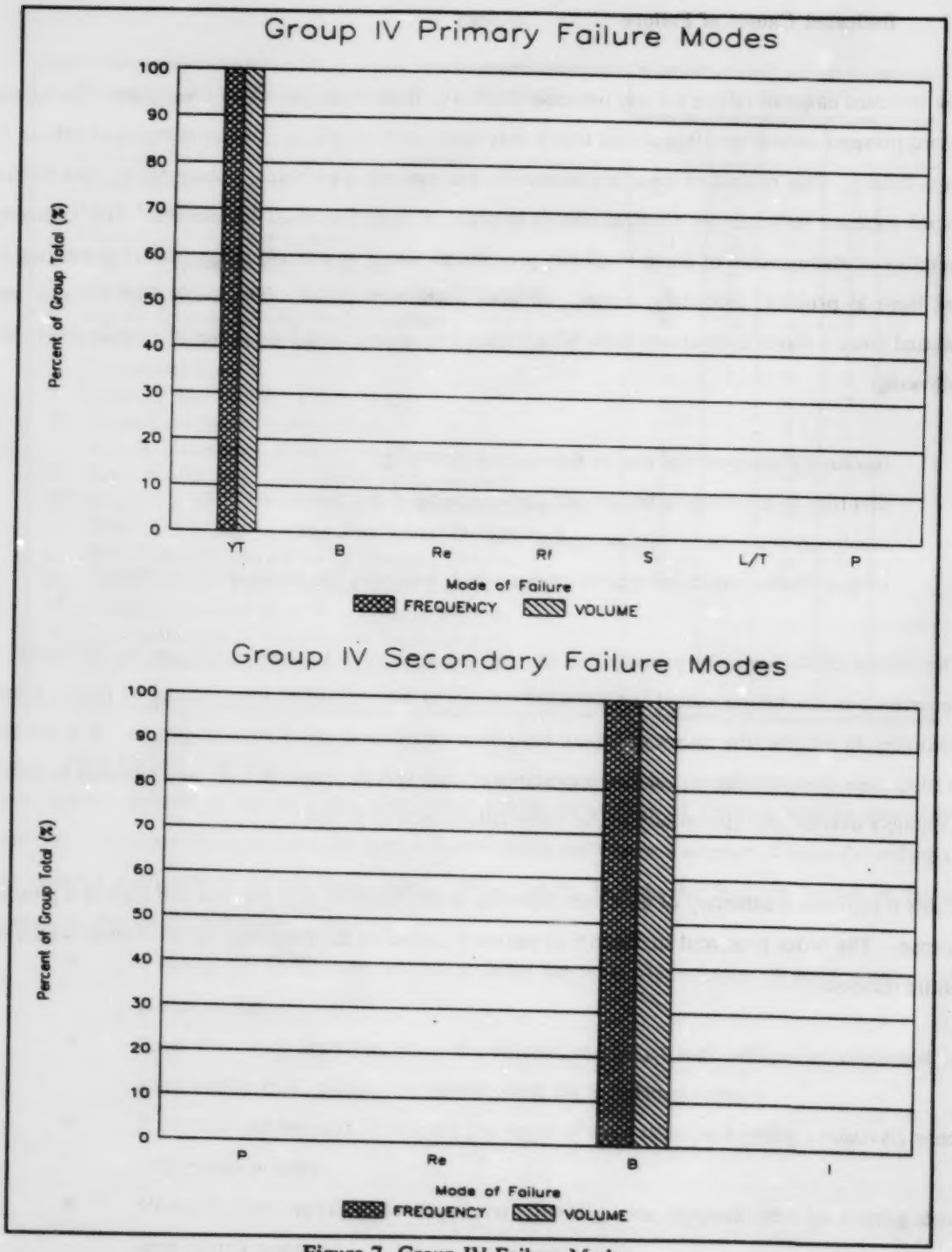

Figure 7. Group IV Failure Modes

3.2 Indicated Causes of Failure

The indicated cause of failure for any one case is often difficult to assess. As a consequence the failure record presents several possible causes which may have acted singly or as a combination of effects to cause failure. This method of reporting minimizes bias towards a particular failure cause. The failure record database indicates the reported causes in order of their perceived importance. The following summary of major causes of dump instability presents all causes as a single group without attempting to link them as primary, secondary, tertiary, or even quaternary causes. This method of analysis was selected since a direct comparison from failure record to record cannot be reasonably made due to the following:

- inaccuracy and potential bias of the original reporting;
- diversity in reporting technique and understanding of the failure reporter;
- combination effects of various causes; and
- unquantifiable aspects of specific causes which indirectly impact on dump stability.

The failure cause summary presented in the following sections is based solely on the incidence of occurrence in the failure record, in a similar manner to that employed for grouping of failure events according to volume, the causes of failure have been categorized into 4 separate groups. It is felt that it adequately demonstrates the relative importance of each specific cause as it pertains to mines in British Columbia overall, and specifically to the dump failure volume groups.

Table 6 provides a summary of all causes reported in the database, and presents this data in a grouped format. The order presented in Table 6 of causes is sorted on the frequency of occurrence within the entire database.

Table 6

Frequency of Occurrence - Indicated Causes of Failure	Group				
	Total	I	II	III	IV
1. Poor Quality Material	22	2	14	6	
2. High Loading Rate	18	3	12	3	
3. Generally Steep Topography	11	2	6	2	1
4. High Precipitation Prior to Event	10	2	6	2	
5. Foundation Recharge (Spring Melt/Precipitation)	9	2	5	2	
6. Known Seepage Springs in Foundation	8	3	4	1	
7. Strain Induced Pore Pressure/Stress Redistribution	7	2	2	2	1
8. Unconfined Toe	6	1	4	1	
9. Planes of Snow or Ice within Dump	6	1	3	2	
10. Weak Foundation Soils at Toe	5	1	2	2	
11. Frozen Foundation Soils under Dump Toe	5		3	2	
12. Saturated Surface Soils/ Snow on Foundation	4		3	1	
13. High Foundation Pore Pressure (Cause undetermined)	4		4		
14. Continued Dump Loading after Initial Deformation	3		3		
15. Pore Pressure Generation in Previous Debris	2		2		
16. Strain Induced Pore Pressure (Low Dumps Only)	2		1	1	
17. Dump Crest Developed in a Convex Manner	1				
18. Overestimation of Foundation Shear Strength	1				
19. High Allowable Deformation (Strain) Rate	1				
Total Number of Causes Reported	125				

3.2.1 Poor Quality Material

Poor quality material is typically that with either a high percentage of fines or readily degradable particles. These low strength materials may influence dump stability in a number of ways depending on the dumped configuration of the weak mass. These modes include the frequent modes of failure previously discussed, including;

- Yielding toe (YT), fines placed at dump toe area with subsequent good quality rock placed on top.
- Basal (B), fines deposited along the foundation contact with subsequent placement of good quality rock, plane of weakness along the foundation contact.
- Rotational embankment (Re), mass placement of weak material forming a relatively weak homogeneous dump.
- Sliver (S), fines rapidly end-dumped and exhibiting some apparent cohesion causing short term oversteepening.

- Planar (P), fines deposited on the dump face with subsequent placement of good quality rock forming a plane of weakness.

3.2.2 High Loading Rate

High loading rate refers to the rapid and intensive placement of material along one specific section of a dump crest length, or to the rapid development of a dump. Loading rate affects the stability and deformation response of the material, however this is also material dependant. High loading rate is most commonly associated with relatively short term toe stability problems related to the generation of high pore pressures in foundation soils at or near the dump toe. In this scenario, the most likely primary mode of failure is yielding toe causing loss of support for the unsupported mass above the toe and the subsequent secondary mode of failure.

Rapid loading will also cause the occurrence of oversteepening in poor quality material leading to the possibility of less severe but more rapidly occurring sliver type failures.

3.2.3 Generally Steep Topography

Steep topography offers low foundation shear resistance support and confinement for dump development, especially if the confinement is impaired at the toe. Driving shear stresses are also greatly increased due to gravitational effects. Steep topography is associated with a number of failure events where the observer has concluded the dump material may have been otherwise stable.

3.2.4 High Precipitation Prior to Event

Precipitation in excess of normal amounts can have an impact on mine dumps in several different ways, however it is not always the only cause of failure. High precipitation often occurs in combination with another cause such as poor material quality, low permeability, and/or poor foundation conditions which may initiate failure. Many dumps exhibit significant deformation response to high precipitation. Data regarding precipitation as a critical cause is included in the failure database.

Precipitation amounts which do not immediately influence deformation often exhibit a lag time indicative of the time required for the water to runoff mine working areas and slopes, collect within the dump, or significantly recharge the groundwater supply at foundation seeps and springs.

The placement, handling, or rehandling of fine grained soils during periods of intense rainfall can also contribute to major instability. This material is very susceptible to water addition, and the handling process effectively mixes and further wets the material.

3.2.5 Foundation Recharge (Snowmelt/Precipitation)

Foundations with known or suspected seepage points or springs may show significant increase in water capacity and consequent seepage pressures into a dump and along foundation contacts during periods of snowmelt and or high precipitation. The modes of failure consistent with this cause include yielding toe (pressures may be highest here), basal along a blinded foundation contact, rotational through foundation material, and liquefaction type failures of loose foundation material.

Efforts should be made to investigate and locate potential seepage sites prior to dump development. Some form of seepage control such as a constructed drain should be considered.

3.2.6 Known Seepage Springs in Foundation

As indicated above, the presence of foundation springs can have a detrimental effect on embankment stability. Knowledge of foundation springs prior to dumping should focus the foundation investigation program to evaluate these features prior to dumping.

3.2.7 Stress Redistribution/Strain Induced Pore Pressure

Rapid redistribution of stresses (which may induce very significant excess pore pressure), or strain induced pore pressure generation as previously described, are both probable causes for many yielding toe failures. Their frequency of occurrence is not high for causative factors, however they have been attributed to very large failure events with extensive runout and are therefore important considerations.

3.2.8 Unconfined Toe

Confinement is important to stability, especially in the toe area as previously described. Dumps which are developed at a site which offers little support or confinement for the toe material will likely be subject to ongoing deformation of the dump. In many cases the failure caused by low confinement of the toe was a temporary problem. For example, if a dump is constructed over an area of unconfined slope and ultimately toes-in to the opposite valley wall as the dump is developed. In the case of this acknowledged instability for a short period of dump development, special operating guidelines should be established to

minimize the risk to personnel, equipment, and the environment of this type of failure.

3.2.9 Planes of Snow or Ice within Dump

The capture of snow and ice during dump construction is an obvious problem for mines in British Columbia. The development of a continuous plane, or of a zone of ice is detrimental to dump stability and should be avoided. Large snowfall accumulations must be removed from the dump platform and placed in a suitable location.

Dumps which contain planes of snow have failed according to a planar mode, along the plane of weakness. This mode is most often a secondary mode and occurs when toe support is lost.

3.2.10 Weak Foundation Soils at Toe

Weak foundation soils at the dump toe may cause a variety of stability problems for dump development. These problems may include liquefaction of these soils upon rapid loading, or simply increase the potential for rotational type failure through the foundation as a primary mode. Weak soils at the toe will also be sensitive to pore pressure caused by groundwater recharge during periods of intense rain or snowmelt. One such record includes the failure of a large sidehill fill dump constructed on relatively good slope conditions. The toe of the dump however was developed onto weak lacustrine or glacial lake sediments. The toe failure was followed by retrogressive failure of the dump in a slow flow movement.

3.2.11 Frozen Foundation Soils under Dump Toe

As previously described, foundation soils which freeze prior to material placement may be susceptible to pore pressure related failure in the foundation during periods of intense recharge. The dump material effectively insulates the frozen layer causing the formation of a lower permeability zone at the foundation contact. As groundwater flow causes recharge and increase in pressure below the dump the ability to drain or dissipate these pressures is severely retarded. Failure probably originates in the toe area, where pore pressure is the highest, and where dump load is the lowest. Failure of the toe is followed by subsequent failure of the mass above or progresses to a continued failure along the foundation contact, depending on the extent of the excess pore pressure and corresponding degree of strength reduction.

3.2.12 Saturated Surface Soils/ Snow on Foundation

In a similar manner to that described for weak foundation soils at toe, the presence of saturated soils or

snow cover on the foundation at the time of construction may lead to the generation of foundation pore pressures which are not dissipated at a sufficient rate to overcome the material loading rate.

3.2.13 High Foundation Pore Pressure (Cause undetermined)

Several records indicate that high foundation pore pressure were evident causes of failure. While the quantity of pressure remained unknown even after failure, visual observations of the foundation draining from seepage points, or from saturated foundation soils displaced with the failure debris have been made.

3.2.14 Continued Dump Loading after Large Deformation

A few cases exist where crest deformations have occurred without the onset of catastrophic failure. Subsequent to these deformations the operators placed further lifts on the platform to maintain the dump grade. This subsequent loading was recorded to have caused massive instability and failure of a much larger volume of material than was originally deforming.

After a dump platform deforms and apparently ceases movement, some time should be allowed prior to continued dumping to ensure the deformation has stopped and to allow the mass to stabilize. More importantly, some effort should be made to determine the underlying cause of platform deformation prior to any further dumping to avoid a potentially catastrophic failure.

3.2.15 Pore Pressure Generation in Previous Debris

Several dumps developed on previous failure debris consisting of overburden rock and natural soils were susceptible to weak foundation condition type deformations and instability due to the presence of that material. If dumping is required on this type of foundation condition, preparation, including the improving the drainage of this material should be carried out.

3.2.16 Strain Induced Pore Pressure (Low Dumps Only)

Strain induced pore pressure in several low dumps has been theorized to be a probable cause of some failures. This mechanism includes the displacement of dump and foundation material on top of a discreet soil stratum, causing an increase in pore pressure. The following failure may resemble a liquefaction/translation type mode.

3.2.17 Dump Crest Developed in a Convex Manner

Dump geometry is of critical importance to stability. Some dumps have been developed as a promontory or a dump 'nose'. This essentially provides an unconfined geometry for the dump material and is susceptible to related modes of failure.

3.2.18 Overestimation of Foundation Shear Strength

Overestimation of foundation shear strength has been identified by back analysis of dump failure where the shear strength of the foundation and associated foundation conditions was lower than originally estimated. This type of design oversight is unnecessary and can be avoided with a modest and appropriate foundation investigation program prior to dump development and the selection of reasonable friction values for foundation soils.

3.2.19 High Allowable Deformation (Strain) Rate

Operating limits currently in use at several mine sites allow sufficiently large strains to occur that the potential for accelerated material degradation and change of particle shape are likely to occur. This may result in a reduction in the material strength. In addition, the development of shear planes within a dump will act as distinct planes of weakness exhibiting a planar mode of failure. This type of failure event cannot be reasonably back analyzed with limit equilibrium methods due to the strain related phenomenon (strain softening) involved.

Other mechanisms such as the rapid redistribution of stress mechanism may be more likely to occur as a result of the rapid placement and associated high strain rate of dump material.

4.0 FAILURE AVOIDANCE

None of the dump failures recorded are the result of an 'act of God'. Indeed the database indicates that most failures are the result of inaccurate design assumptions, or because of changes in operational conditions, including material properties. For these reasons it is clear that almost all failures can be avoided if there is a commitment so to do.

4.1 Design Considerations

Mine dump designs are universally based on a simplified two-dimensional limit equilibrium analyses to assess stability. These structures are usually assumed to be in a drained state, even during periods of high precipitation or runoff. A number of simplifying assumptions must be made for most stability analyses. It should be reasonable to expect that instability may occur if any or all of these assumptions were invalid. This is especially true in the case of dumps which exhibit marginal stability in the factor of safety calculation. Failure ranging from minor deformation to large scale catastrophic failure may occur due to subtle variations in these assumptions or the compounding effect of several errors in the dump design assumptions.

4.1.1 Foundation Investigation

A site investigation into the conditions of the foundation will often be carried out during design of a new dump. The level of effort in this investigation has generally been minimal, except in the instances of dump construction on very weak lacustrine soils. Even in this case, detailed investigation and evaluation of the foundation has not been carried out for all such failures recorded in the database.

The level of effort which goes into most foundation investigations for mine dump sites is far less than is commonly carried out for other large rockfill projects where stability must be ensured. To date, foundation investigations have been very limited as compared with the ultimate size, and associated cost of potential failure. These associated costs to the mine could include direct fines or penalties, the operating costs related to loss of dump availability, and, in the ultimate case, potential injury or death to workers.

The Provincial design guidelines (MEMPR, 1991a) offer some details with respect to foundation

investigation programs and techniques, however, the required extent of an investigation program is not immediately apparent. Since the foundation investigation provides a basis for an estimation of the foundation material strength, which may vary across a broad site, it would be prudent to carry out a thorough evaluation of all foundation conditions. This would be in contrast to assuming an average foundation condition supported with a minimum of actual site investigation.

4.1.2 Material Strength Assumptions

Material property assumptions are made almost universally without the aid of actual strength measurements. The industry accepted angle of friction (ϕ') for almost all mine dump material is 37°, and is essentially based on the angle of repose of fresh material, indicating the short term strength of the blasted rock. In the long-term, natural degradation of the rock will cause a reduction in strength. This process may be accelerated by high strains incurred with high loading rates, or by other factors such as dump height. In reality the strength of the material mixture in a long-term sense is overestimated for the purpose of design.

4.2 Operational Considerations

Operational practises or changes to dump construction methodology should be assessed with respect to the dump design. In many cases the dump design makes assumptions with respect to foundation conditions or material quality which may be altered due to differences in the assumed operation of the dump.

4.2.1 Changing Material Properties

The dump material may vary from time to time, such that the assumption of placing an entire dump of homogeneous material is fundamentally in error, as is assumed for all mine dump stability assessments. The placement of a large volume of poor quality material within a specific part of the dump, or onto the face of a dump will cause a variety of instability features or failure modes as described previously. None of the failed dump designs had any specific guidelines or measures for the handling of this type of material, and thus when the material was dumped it was perhaps unwittingly placed in the worst possible manner for dump stability. Optimized dump placement plans can be beneficial to operators if dump failures are to be avoided.

4.2.2 Excessive Loading Rate

Dump designs do not typically specify maximum allowable loading rates to ensure stability. This is due, in part, to the highly anisotropic and heterogeneous nature of the structures. However, reference is made to an arbitrary (although commonly accepted) value of 200 BCM/m/d (Bank Cubic Metres/m of crest/day) as a credible limit for all dumps, regardless of height. The intent of this value is to prevent the occurrence of pore pressure generation in foundation soils, and in this regard may be well suited for conditions at some mine sites in British Columbia.

In addition, loading rates in excess of the ability of the material to consolidate and attain optimum strength may cause very large scale deformations leading to the proposed mechanism of redistribution of stress, and causing yielding toe failure. In reality, the best loading rate is very site specific as it is dependant on the dump configuration and strengths. It should be recommended as a matter of course that every effort should be made to control loading rate. This could be achieved by increasing crest lengths, dumping to alternate sites, or by enhanced mine planning such that an overburden rock placement schedule can be optimized.

4.3 Stability Calculations

Conventional methods of stability analysis are described in the Provincial investigation and design manual, (MEMPR, 1991a).

4.3.1 Modes of Failure

The modes of mine dump failure described, and the associated methods of stability analysis have proven relatively useful for many historical failures, but these did not involve the analysis of such large structures in such precarious foundation situations as are observed today. Loading rates and topography at many dump sites may make them prone to high deformation rates, which in turn may lead to the redistribution of stress mechanism previously described. This type of mechanism may be responsible for a large proportion of the failures. In these cases, the assumed modes or models of stability are too simplistic a method of analysis for many of the dump deformations, which ultimately lead to failure.

4.3.2 Limitations of the Limit Equilibrium Analysis of Mine Dumps

Analysis of these structures operated under the conditions described above cannot be modelled accurately

using conventional limit equilibrium techniques. Of primary consideration is the fact that limit equilibrium techniques assume that a given shear strength is mobilized along all points of a given slip surface. In other words, these models do not allow the use of constitutive relationships for materials and are therefore not strain compatible. Limit equilibrium is thus compromised by ignoring the real variation in mobilized strength, which is a function of strain, along the slip surface. This can be extremely non-conservative where the dump materials are severely strain weakened and the limit equilibrium analyses are based on peak or near peak effective strength parameters.

The double wedge method has been offered as a useful limit equilibrium model for stability analyses. Previous discussion related to the redistribution of dump stress, including the interaction of a toe wedge or block, and the active wedge, are based on the concepts of the double wedge mechanism. However, the strain incompatibility between these two wedges negates the validity of the limit equilibrium approach, which without a more appropriate analytical tool, presents the designer with a highly judgemental choice of the wedge contact configuration. Fortunately, the analytical procedures required to accurately evaluate actual dump conditions are becoming available, and will be discussed further in this document.

In general, limit equilibrium analysis of mine dumps which are rapidly constructed may not be capable of incorporating the differences in placed density and strength which are shown to take place due to rapid loading. Furthermore, accurately predicting pore pressure conditions is beyond most common analytical capabilities. Without accurate pore pressure conditions, effective stress limit equilibrium analyses are meaningless.

4.3.3 Estimates of Pore Pressure and Phreatic Surface

Mine dumps have been universally analyzed as entirely drained structures. The basis for this assumption is set out in previous sections. The ramifications for stability of a dump if the saturation level rapidly rises, or is perched at some elevations are extremely negative. Serious consideration of the long-term effects of material degradation, fines generation related to loading rate induced strains, and the short-term zonation of fines near the foundation contact should be made during the stability analysis.

4.4 Dump Stability Rating Scheme (MEMPR, 1991a)

The Mine Dump Stability Rating Scheme proposed in the Provincial Interim Investigation and Design

Guidelines (MEMPR, 1991a) has been applied to each dump failure record. The scheme effectively rates dumps of various heights and volumes, many of which have a rating in excess of 1300. No immediate trend between failure mechanism or volume of failure and the dump rating has been observed. Further refinement of the rating scheme may produce better correlation of these factors .

The Dump Stability Rating Scheme provides a very low rating (implying relative stability) of all of the failed lift-constructed dumps. All of these were less than 45 m in height and constructed on weak lacustrine soils. The rating scheme in its present form therefore is not capable of properly assessing these types of dumps and foundation conditions in relation to failures of other dump types and their associated ratings, For this reason, the rating scheme proposed by Piteau (1991) should be used with careful judgement. Future refinements of the scheme should incorporate a means of accounting for the inequities observed in the rating of failed dumps included in the database.

5.0 RECOMMENDATIONS FOR FUTURE RESEARCH

The state-of-technology with respect to mine dump design and operation is based almost entirely on field experience. The technology has been limited in its development due to the lack of accurate record keeping, analysis and subsequent assessment of dump behaviour and failure. This is primarily a function of the industry-wide concern regarding the cost and benefits associated with improving dumping technology. The following discussion identifies areas for future research to improve the understanding of dump behaviour and reduce the potential for operator risk due to dump instability.

5.1 Deformation Modelling

Since a key mechanism causing dump failure has been identified as deformation leading to redistribution of stress and excess loading of the toe block, further research is required to confirm the extent of this phenomenon within mine dumps. This may be achieved using modern deformation analysis software to properly simulate the development of a rapidly loaded embankment. The model should be calibrated with an actual dump to verify the deformations observed in the model. Although, verification may not specifically have to include failure of the control dump or the model. The model may then be used to demonstrate stress redistribution, the passive toe block, and the increase of loading on the toe block once large scale deformations begin.

5.2 Foundation Pore Pressure Monitoring and Modelling

The behaviour of foundation pore pressure response to the variety of known influencing factors requires immediate research and discussion. This may be achieved by more intensive monitoring programs correlated with changes in site conditions, including operating conditions and climate. Pore pressure modelling may also be carried out using computer simulation in a combined manner with deformation modelling described above. Several such programs are currently available to carry out this task.

5.3 Modifications to the Dump Rating Scheme

The application of a dump rating scheme which attempts to incorporate the major factors which affect stability of dump structures is very difficult. The dump rating scheme will require refinement as more

cases are investigated. In its present form the scheme may not be capable of demonstrating the real likelihood of failure, however as a guideline for assessing the risk of failure, the scheme provides a good overview of the most pertinent design factors.

6.0 CONCLUSIONS

Several conclusions have been reached with respect to the evaluation of the failure record database and a review of available literature. These conclusions are not necessarily co-dependant and are therefore presented in the following format:

- Mine dumps represent some of the largest and tallest geotechnical structures in the world, the corresponding level of effort for investigation and designs however, would imply that these structures are relatively insignificant. This is a function of the respective mine cost of dealing with the material, and highlights the conflict between ensuring geotechnical stability of dumps and maintaining the profitability of the mine. In some cases guaranteeing stability of mine dumps could significantly impact on the viability of the mine itself due to the associated cost. Conversely, both direct and indirect costs of dump failure could be many times the cost of designing and constructing a stable dump; each case should be assessed in isolation in terms of cost/benefit.

- While the impact of a failure within the bounds of a permitted dump area may have little impact, and may have been predicted such that men and machinery were not involved, the cost of additional temporary haulage distances and the loss of availability of a dump should be considered. This cost can only be appreciated by the mine, but is anticipated to be significant. In this case all efforts should be made to reduce loading rate, ensure proper placement given material characteristics, and to generally follow procedures for minimizing instability, as described in the operating guidelines (MEMPR, 1991b).

- Dumps cannot be considered as homogeneous isotropic masses since they are not constructed in a manner that would produce this effect. Realization of this concept should enable designers and regulators to critically assess the adequacy of the conventional (and typically inappropriate) method of stability analysis typically used. In this way, the assessment of a large geotechnical structure should include research into the deformation characteristics of rapidly loaded dumps under typical conditions found at mines in the Province.

- The dynamics of these large fill structures constructed by end-dumping are poorly understood and

have not been well investigated. The combination of material consolidation, material degradation, continuous loading of loose material, redistribution of internal stresses, and foundation interaction, cause dump deformations which are unique to high end-dumped structures, and which may lead to ultimate instability.

- As mining rates have increased and the demand for adequate dump sites has caused rapid loading of existing dumps, many mines have compensated by increasing the monitoring limits, simply to increase the dump availability. The original limits at mines were set arbitrarily and have been increased as mine operators have gained experience with the deformation response of the material and dump geometry. As monitoring limits have increased so has the dump height at many mine sites, such that a monitor system for a dump of up to 400 m in vertical height is monitored using 25 to 50 m of wire to record crest movements. In reality, the ability to monitor even relative crest movements along the wire, and predict failure by means of plotting crest acceleration has proven more effective than might have been expected. Indeed most cases of instability have been forewarned by such equipment, even in the absence of absolute displacement measurement, and even in the case of very large block movements which may have included all of the monitoring equipment. In addition, it is evident that the measurement of movements in the field have not, in many instances, measured the maximum directional component. This is essential where an allowable movement criteria is used.

  General confirmation for instability related to rapid placement and high allowable deformations is the general increase in the number of failures which have occurred since the increase in allowable monitoring limits.

- Mine operators of remote dump sites with high loading rates and coincident instability are promoting the concept of *controlled failure*. This concept includes the use of intensive crest monitoring to identify times of potential instability. This concept became popular in response to the inability of dump designs to assess and ensure stability under operating conditions in excess of previous precedents. The role of deformation monitoring and calibration with computer modelling techniques will be of critical importance in this regard. The ability of conventional stability assessments for these structures is shown to be fundamentally in error and should be abandoned for dumps which will be known to operate under very high loading rates. By

presenting a factor of safety implying stability of the structure, the designer fails to properly assess the real structure deformations which may lead to ultimate failure in an uncontrolled manner.

- The database indicates that failure resulting from a combination of modes generally produces more voluminous events. The implications of this are that primary modes which are related to high rates of deformation should be avoided by reducing the primary cause of the mechanism.

- Dump crest lengths should be made as long as possible to minimize loading rate related instability. This may include the permitting of additional areas to increase the available dump crest length.

- The application of block models which are typically used to model mine orebodies and schedule mining operations should be assessed as a possible means of scheduling the mining and placement of overburden rock in dumps. This could include the development of dumps which would contain a specific material quality, where the schedule of poor quality rock dumping could be planned in advance, and placed in an appropriate dump site.

- The research committee should establish a task force which could be mobilized to immediately review large dump failures. The group could ensure that accurate investigations and records are made with respect to the analysis of the event. In addition the group could identify a specific dump development in the Province which could be used as a test site for detailed monitoring and analysis of deformation response, to further the understanding of dump behaviour. This test site may also include the investigation of foundation contact conditions over time to assess the permeability of the structure with respect to stability considerations.

- In general, the level of reporting of dump failures has varied dramatically from inadequate reports to reports which may or may not include sufficient detail to accurately assess the failure. The level of effort of reporting should be increased across the Province, and should as a minimum include the salient details required to make an assessment. A summary of these details can be found in the Provincial Operating and Monitoring Guidelines (MEMPR, 1991b).

Mine dump stability in the Province will only be improved through the accurate recording of construction details, monitoring, and subsequent assessment of failure events, it is of critical importance that operators and consultants alike carry out these tasks in a manner which may be used for future assessment, and to permit the updating of the dump failure database with accurate and complete information. The mining industry in the Province is challenged by increasing concerns about public safety, environmental impact, and economic viability. To remove the design and operation of mine dumps from a poorly understood practice to a clear, concise, and technically sound framework can only benefit the Industry and the Province in the long-term.

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APPENDIX A
Draft Failure Record Database

DATABASE LEGEND

Note: Each record in the database refers to one failure event. Six mines are included in this database and are referred to by a letter code from "A" through "F". For each mine there may be several dump failures, each of which is designated by a letter code.

TOPOGRAPHY

Slope angles for original topography are provided for the height of the dump, divided into thirds (as crest slope, mid slope, toe slope), and expressed in degrees from the horizontal. These values refer to the foundation slope.

MATERIAL PROPERTIES

UCS - Uniaxial Compressive Strength (of intact rock material)

DESIGNATION	UCS (MPa)
Very High	>200
High	100-200
Medium	50-100
Low	25-50
Very Low	10-25

ESTIMATED STRENGTH

$\phi'(^{\circ})$	effective friction angle
c'(kPa)	effective cohesion intercept
s_u	undrained shear strength (for normally consolidated clays)

DURABILITY

SD	slake durability test
LA	Los Angeles Abrasion Test

PARTICLE SIZE

> 300 mm (%)	Percent passing 300 mm
< # 200 (%)	Percent passing No. 200 mesh

OTHER

BCM	Bank Cubic Metres

MINE DUMP FAILURE SUMMARY — RECORD NO. 1

MINE: A - Open pit coal
DUMP NAME: A - Active at time of failure.
DATE OF FAILURE: June 29, 1982
DUMP HEIGHT: 150 m
FAILURE VOLUME: 575,000 m^3
RUNOUT DIST.: 1200 m (average 10° runout slope)

GENERAL DATA:

Topography — Toe slope = 25°; mid slope = 18°; crest slope = 36°; concave at top, convex at bottom.

Geometry — Unconfined sidehill fill, no 3D wedging effect, linear in plan.

Foundation — High slopes with varying thickness of silty sand and gravel colluvium, visible coal bloom at some locations. Alluvial sand and gravel slopewash with fine sand and silt evident on lower slopes.

Construction — End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH φ'(°), c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	<#200
SANDSTONE (48)	100	37°, 0	HIGH	75	2
SILTSTONE (33)	55		MODERATE	50	10
MUDSTONE (19)	30		LOW-MODERATE	40	15

DESIGN ASSUMPTIONS:

Material Strengths — Dump $\phi'=37°$, $c'=0$; Foundation $\phi'=33°$-$39°$, $c'=0$
Piezometric Assumptions — Drained
Method of Stability Calculation — Sarma
Design Safety Factor — ~1.0 (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
100-200 m = 100	1-50 Mm^3 = 50	37° = 100	25-32° = 100	100	100
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
200	200	200	100	0	**1250/1800**

FAILURE DETAILS:

Loading rate — Loading rate not considered a factor of instability.

Monitoring — Vertical displacement of 1.5 m/day for one day prior to failure. Displacement monitoring by survey levelling, vertical component only.

Climate Data — Precipitation may have influenced stability; recorded 40 mm rain prior to failure, causing infiltration and ground water recharge.

Indicated Mode — Failure along foundation contact in toe zone (unconfined), causing loss of support and planar failure through dump along plane of weakness.

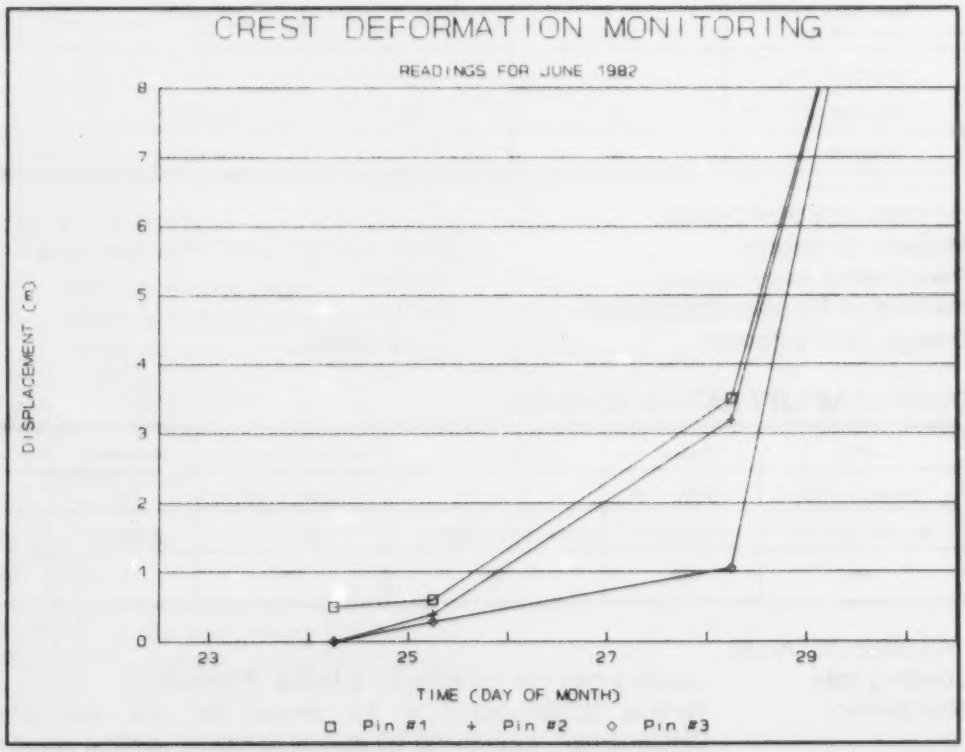
Indicated Cause — Steep foundation slope with unconfined dump toe; snow in dump forming weak plane; precipitation elevating internal pore pressure and increasing foundation seepage pressure; poor quality material with high fines content.

DISCUSSION

The primary cause of instability appears to be the limited support for the dump in the toe region. The initial toe failure may have also been influenced by precipitation, meltwater from contained snow and ice, and groundwater recharge during spring melt. These factors can result in elevated pore pressure within the dump, increased loading, and foundation seepage pressures at lower levels, specifically the toe region.

The second stage of failure occurred due to loss of support as a result of the failure of the toe. New stresses develop and failure can occur along a surface where the material shear strength is overcome, or as in this case, a continuous plane of weakness exists. Snow captured during dump construction in winter months will form a plane parallel to the dump face, and will be insulated from thawing for several months by the mine rock itself.

A high percentage of fines were observed at the failure scarp, indicating that for some period of time dumping of poor quality material had taken place. In this case it may have coincided with the capture of snow, and may have further reduced overall stability by causing a perched phreatic surface.



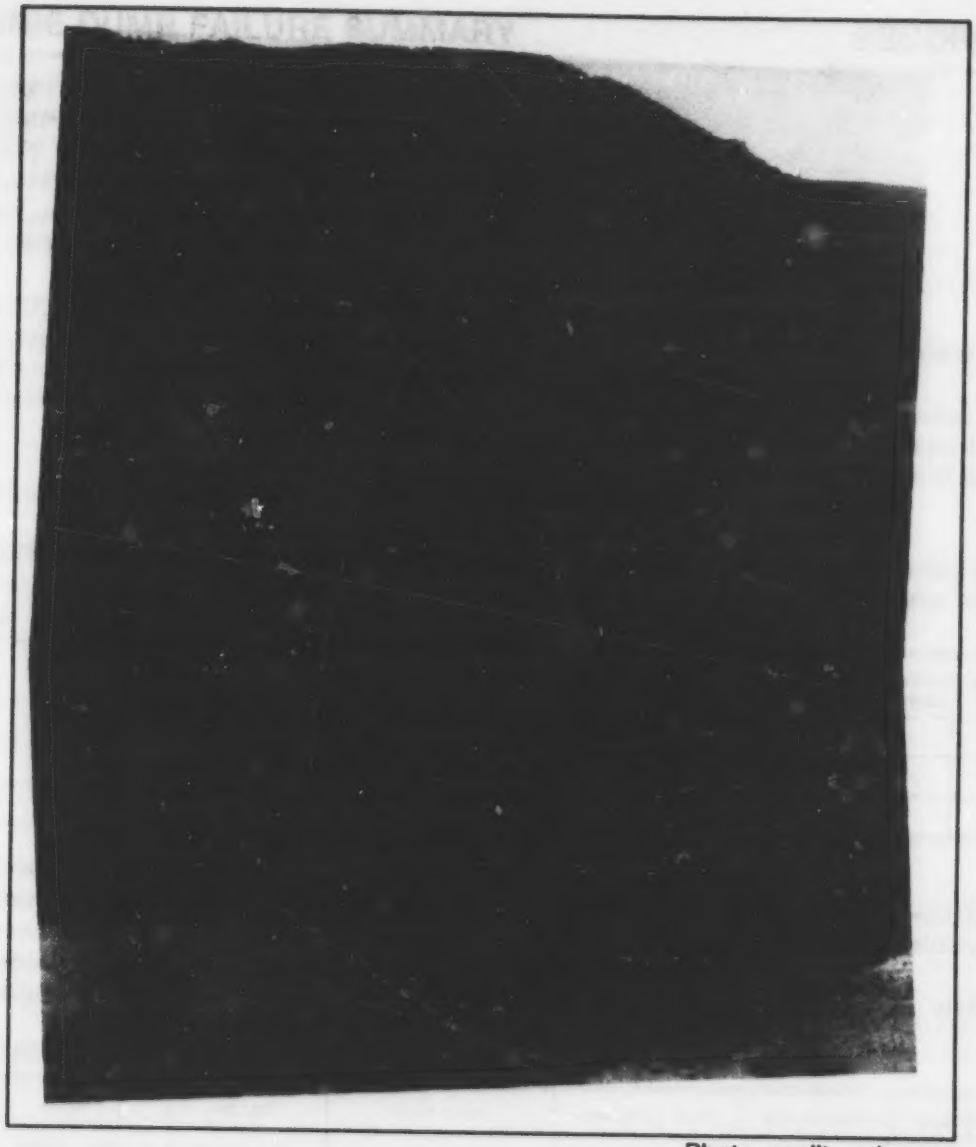


Photo credit: unknown

Photograph 1: Record 1 dump failure and runout.

MINE DUMP FAILURE SUMMARY — RECORD NO. 2

MINE: A - Open pit coal
DUMP NAME: B - Active at time of failure.
DATE OF FAILURE: November 24, 1968
DUMP HEIGHT: 210 m (crest at elev. 4800 feet, toe at elev. 4100 feet)
FAILURE VOLUME: 150,000 m^3
RUNOUT DIST.: 550 m (average 11° runout slope)

GENERAL DATA:

Topography Toe slope = 22°; mid slope = 34°; crest slope = 40°; concave in profile.
Geometry Unconfined sidehill fill, minor 3D wedging effect
Foundation Varying thickness of colluvial sands and gravels above elevation 4500 feet. Springs were observed in creek gully at the elevation of the pit and below. Below 4500 feet glaciolacustrine clayey-silt, sand, and gravel exist.
Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests. The dump is composed primarily of blasted rock from the adjacent pit, however some overburden soils, including fines and organics, were placed in the dump.

DUMP ROCK TYPE (% BY VOLUME)	UCS (Mpa)	ESTIMATED STRENGTH ϕ'(°), c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	PARTICLE SIZE (%) <#200
SANDSTONE	100	38°, 0	HIGH	75	2
SILTSTONE	55		MODERATE	50	10
MUDSTONE	30		LOW-MODERATE	40	15

DESIGN ASSUMPTIONS:

Material Strengths Dump ϕ'=38°, c'=0; Foundation ϕ'=30-38°, c'=0
Piezometric Assumptions Elevated piezometric conditions considered.
Method of Stability Calculation Not reported
Design Safety Factor ~ 1.0 (elevated piezometric pressure, static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
>200m = 200	1-50 Mm^3 = 50	37° = 100	>32° = 200	100	200
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
200	200	200	100	0	1550/1800

FAILURE DETAILS:

Loading rate Loading rate not considered a factor of instability.
Monitoring No instrumentation during dump main failure.
Climate Data Heavy rainfall preceding failure, heavy snowfall contained in dump during construction in previous winter, forming a continuous plane of weakness.
Indicated Mode Failure along foundation contact in toe zone causing loss of support and failure through dump along plane of weakness.
Indicated Cause Weak lacustrine foundation soils at the toe area; snow in dump forming weak plane; precipitation elevating internal pore pressure and foundation seepage pressure; steep foundation slope.

DISCUSSION

The weak glaciolacustrine sediments present at the lower portion of the dump failed when a combination of high load and high piezometric pressures were incurred. The exact mechanism of failure is not known, but could be related to liquefaction in a local area. Once established in one area, failure could quickly spread throughout the lacustrine deposit via pore water pressure increasing in contained sand and gravel layers. This mode of failure would be rapid, coinciding with eye witness reports, and would be extensive over the weak sediments as load was suddenly applied by the unsupported mass above.

The second stage of failure occurred due to loss of support as a result of the failure of the toe. New stresses develop and failure can occur along a surface where the material shear strength is overcome, or as in this case, a continuous plane of weakness exists. Snow captured during dump construction in winter months will form a plane parallel to the dump face, and will be insulated from thawing for several months by the mine rock itself. Ice layers were observed to be contained in the dump during the excavation of test pits in the material.

Foundation seepage pressures were also important in this event. The dump was constructed on a sloping foundation with a small creek gully down slope. Springs had been observed in the gully, indicating seepage pressures present prior to the dump construction. The high rainfall in the week prior to the failure provided recharge of groundwater and increased seepage pressures out of the springs and under the dump.

The failure occurred in a dump adjacent to another dump structure which did not fail, although signs of instability were evident. The observed deformation and cracking was caused by similar site and dump conditions, however, only the failed dump had a creek gully with observed seepage points in the foundation.

In an effort to stabilize the adjacent dump, horizontal drains were drilled into the foundation. Later, attempts were made to bring about a controlled failure, including adding water directly to the dump while simultaneously blasting the horizontal drains with a regular production pit blast. The attempt to increase the phreatic surface in addition to inducing dynamic vibrations was not successful in promoting a failure, and the dump was later reworked to reduce the potential for further instability.

MINE DUMP FAILURE SUMMARY — RECORD NO. 3

MINE: B - Open pit coal
DUMP NAME: A - Active at time of failure.
DATE OF FAILURE: November 1, 1979 and November 9, 1979
DUMP HEIGHT: 36 m
FAILURE VOLUME: 10,500 m^3
RUNOUT DIST.: 45 m (average 19° runout slope)

GENERAL DATA:

Topography 22° foundation slope from toe to crest, linear in profile
Geometry Narrow unconfined sidehill fill, no 3D wedging effect, linear in plan.
Foundation Veneer of disturbed and saturated mudflow debris over variable thickness of silty sand (average 2 m), some angular sandstone gravel fragments overlying soft (R1) weathered shale bedrock. The bedrock exhibits sub-horizontal bedding planes, and seepage springs have been observed in vicinity of dump failure.
Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH $\phi'(^\circ)$, c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	<#200
SANDSTONE (30 - 40)	153 - 213	37°, 0	LA = 25, SD = 90	70	10
SILTSTONE (50)	79 - 154		LA = 19, SD = 88	50	<5
MUDSTONE (10 - 20)	33 - 60		LA = 15, SD = 98	30	10

DESIGN ASSUMPTIONS:

Material Strengths Dump ϕ'=37°, c'=0; Foundation ϕ'=30-33°, c'=0
Piezometric Assumptions Drained
Method of Stability Calculation Bishop's simplified
Design Safety Factor ~1.0 (adequate pore pressure dissipation of foundation soils required for stability)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
<50m = 0	<1Mm³ = 0	37° = 100	10-25° = 90	100	200
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
100	200	100	100	0	950/1800

FAILURE DETAILS:

Loading rate Rapid loading on narrow roadway, estimated rate of loading of 90 BCM/m/day based on recorded advance of 300 feet in one month.
Monitoring Visual monitoring only at time of failure.
Climate Data Precipitation not considered a primary factor of instability.
Indicated Mode Lateral yielding of foundation soils at toe region and basal sliding along foundation contact in a slow creeping movement.
Indicated Cause Rapid loading of soft weak saturated foundation soils causing excess pore pressure generation; foundation seepage pressures.

DISCUSSION

The initial failure at the toe region was caused by rapid loading, leading to inadequate pore pressure dissipation, and lateral yielding due to reduced shear strength. This mode of failure is consistent with the observations recorded, including slow creeping movement and bulldozing of material in front of the toe.

Other factors which influenced further movement once toe failure was initiated include previous mudflow debris at the foundation contact, and high foundation seepage pressures as observed in nearby creek beds. Precipitation was not considered as a direct cause of instability at the time, however it is apparent that saturated foundation conditions existed, and that during this time of year significant rainfall occurs. In addition to elevating seepage pressure by groundwater recharge, precipitation can also increase the unit weight of material, especially fines, contained in the dump. Fines were observed due to oversteepening of the crest imparted by the apparent cohesion of the material.

The failure debris however was primarily coarse loose and dry mine rock, with a smaller proportion of fines and overburden soils. No deleterious materials such as coal fines, wet soil, or snow were observed in the debris.

MINE DUMP FAILURE SUMMARY — RECORD NO. 4

MINE: C - Open pit coal
DUMP NAME: A - Active at time of failure.
DATE OF FAILURE: January 30, 1984
DUMP HEIGHT: 220 m (crest at elev. 1980 m, toe at elev. 1760 m)
FAILURE VOLUME: 775, 000 m^3
RUNOUT DIST.: 140 m (average 11° runout slope)

GENERAL DATA:

Topography 11° slope at toe, concave downward in profile
Geometry Unconfined sidehill fill, no 3D wedging effect, linear in plan.
Foundation One metre thick blanket of colluvial silty sand and gravel overlying dense till. An undetermined quantity of poor quality saturated overburden soil was deposited on the foundation slope sometime prior to construction.
Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH $\phi'(°)$, c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	<#200
SILTSTONE (50)	110	37°, 0	LA = 34 / SD = 98	70	1
SANDSTONE (25)	130		LA = 34 / SD = 98		
MUDSTONE (25)	55		LOW		

DESIGN ASSUMPTIONS:

Material Strengths Dump ϕ'=37°, c'=0; Foundation ϕ'=27°, c'=0
Piezometric Assumptions Drained
Method of Stability Calculation Basal Sliding analysis
Design Safety Factor ~1.0 (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
>200m = 200	1-50 Mm^3 = 50	37° = 100	10-25° = 50	100	200
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
100	200	100	100	0	1200/1800

FAILURE DETAILS:

Loading rate Average loading rate of 60 BCM/m/day prior to failure, peak rates not reported.
Monitoring Maximum allowable operating crest deformation = 1200 mm/day.
Climate Data Precipitation not considered a factor of instability.
Indicated Mode Basal sliding
Indicated Cause Foundation frozen during construction forming an impermeable boundary below dump, with resultant increase in foundation pore pressures during groundwater recharge; slow creeping movement occurring over a period of several hours.

DISCUSSION

The failure was characterized by a 220 m long backscarp 16 m from the original crest and semi circular in plan, with vertical displacement of approximately 70 m. The failure occurred slowly over a period of several hours, during which time grinding rocks could be heard by observers.

Groundwater recharge during periods of intense thaw generate significant foundation seepage pressures, which are generally dissipated through the coarse free draining rock at the foundation contact. If the foundation contact is frozen during periods of recharge, the potential for the generation of high pressures below the dump foundation contact zone is high. These pressures will greatly reduce the shear strength of the natural foundation soils.

The creep-like advance continued due to a combination of foundation pore pressure in frozen areas and soft saturated yielding foundation soils which were not frozen at the time of failure. Frozen foundation soils were observed to be churned up at the advancing toe of the failure.

MINE DUMP FAILURE SUMMARY — RECORD NO. 5

MINE: C - Open pit coal
DUMP NAME: A - Active at time of failure.
DATE OF FAILURE: May 8, 1983
DUMP HEIGHT: 220 m (crest at elev. 1980 m, toe at elev. 1760 m)
FAILURE VOLUME: 140,000 m^3
RUNOUT DIST.: 36 m (average 11° runout slope)

GENERAL DATA:

Topography 11° slope at toe, concave downward in profile
Geometry Unconfined sidehill fill, no 3D wedging effect, linear in plan.
Foundation One metre thick blanket of colluvial silty sand and gravel overlying dense till. An undetermined quantity of poor quality, saturated overburden soil was deposited on the foundation slope sometime prior to construction.
Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH ϕ'(°), c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	<#200
SILTSTONE (50)	110	37°, 0	LA = 34 / SD = 98	70	1
SANDSTONE (25)	130		LA = 34 / SD = 98		
MUDSTONE (25)	55		LOW		

DESIGN ASSUMPTIONS:

Material Strengths Dump ϕ'=37°, c'=0; Foundation ϕ'=27°, c'=0
Piezometric Assumptions Drained (see legend)
Method of Stability Calculation Basal Sliding analysis
Design Safety Factor ~ 1.0 (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
>200m = 200	1-50 Mm³ = 50	37° = 100	10-25° = 50	10+	100
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
250	200	100	100	0	1200/1800

FAILURE DETAILS:

Loading rate Loading rate not considered a factor of instability.
Monitoring Cracking observed 4 days prior, movement less than 500 mm/day.
Climate Data Precipitation not considered a factor of instability.
Indicated Mode Rotational failure through dump material.
Indicated Cause Fine grained poor quality material; crest oversteepening due to apparent cohesion of fines.

DISCUSSION

The failure was characterized by a rotational slump in wet fine grained material. The backscarp was observed to be semi-circular in plan, and approximately 70 m in length. The slump occurred in the top half of the dump face, originating in the area of a slope bulge observed prior to failure.

Dumping of fine grained material was concentrated in the failed area because of favourable geometry and the inherent stability of that part of the dump. The failure occurred within the dump itself, an indication that foundation and geometry conditions remained favourable.

MINE DUMP FAILURE SUMMARY — RECORD NO. 6

MINE: C - Open pit coal
DUMP NAME: A - Active at time of failure.
DATE OF FAILURE: August 15, 1987
DUMP HEIGHT: 220 m (crest at elev. 1980 m, toe at elev. 1760 m)
FAILURE VOLUME: 500,000 m^3
RUNOUT DIST.: 240 m (average runout slope = 11°)

GENERAL DATA:

Topography 11° slope at toe, concave downward in profile
Geometry Unconfined sidehill fill, no 3D wedging effect, linear in plan.
Foundation One metre thick blanket of colluvial silty sand and gravel overlying dense till. An undetermined quantity of poor quality saturated overburden soil was deposited on the foundation slope sometime prior to the construction of the dump, debris from previous failures may also be present.
Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH ϕ'(°), C'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	PARTICLE SIZE (%) <#200
SILTSTONE (50)	110	37°, 0	LA = 34 / SD = 98	70	1
SANDSTONE (25)	120		LA = 34 / SD = 98		
MUDSTONE (25)	55		LOW		

DESIGN ASSUMPTIONS:

Material Strengths Dump ϕ'=37°, c'=0; Foundation ϕ'=33°, c'=0
Piezometric Assumptions Excess pore water pressure dissipation required.
Method of Stability Calculation Basal Sliding analysis
Design Safety Factor ~ 1.0 (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
>200 m = 200	1-50 Mm^3 = 50	37° = 100	10-25° = 50	100	200
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
100	200	100	100	0	1200/1800

FAILURE DETAILS:

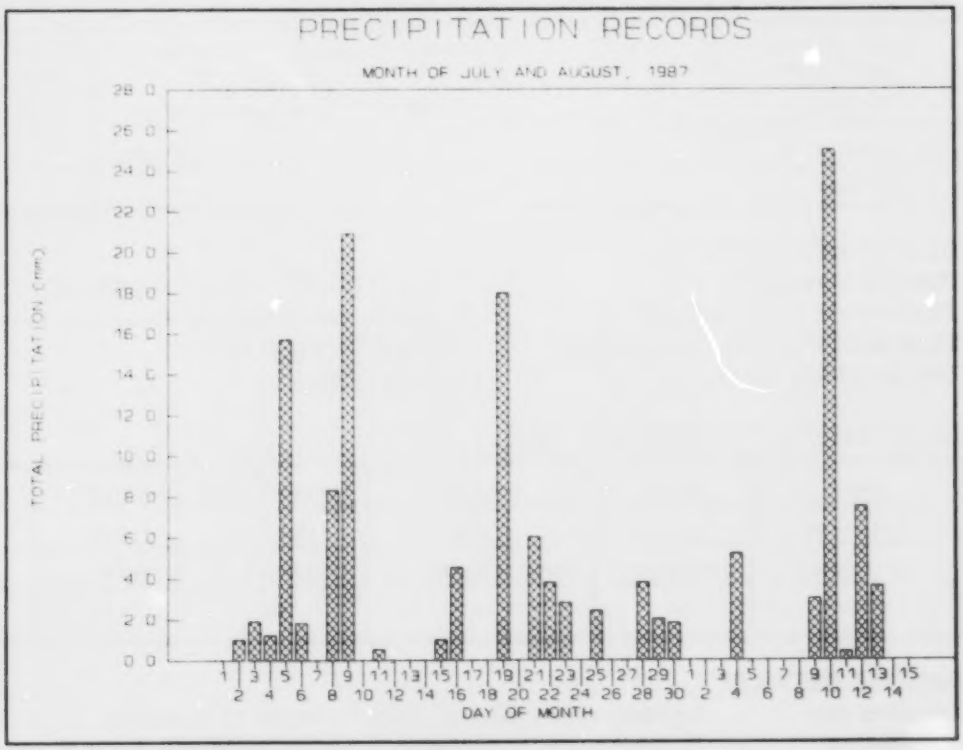
Loading rate Loading rates not considered a factor of instability.
Monitoring Dumping was suspended 5 days prior to failure since rates were above 600 mm/day. Two days previously rates had accelerated to 2350 mm/ day, and to 7000 mm/day just prior to failure.
Climate Data Precipitation records indicate 70 % higher than average rainfall for July and August, including 39.5 mm total for 6 days prior to failure.
Indicated Mode Non-circular rotational slump.
Indicated Cause Foundation frozen during construction forming an impermeable boundary below dump; high precipitation with resultant increase in foundation pore pressures; slow creeping movement.

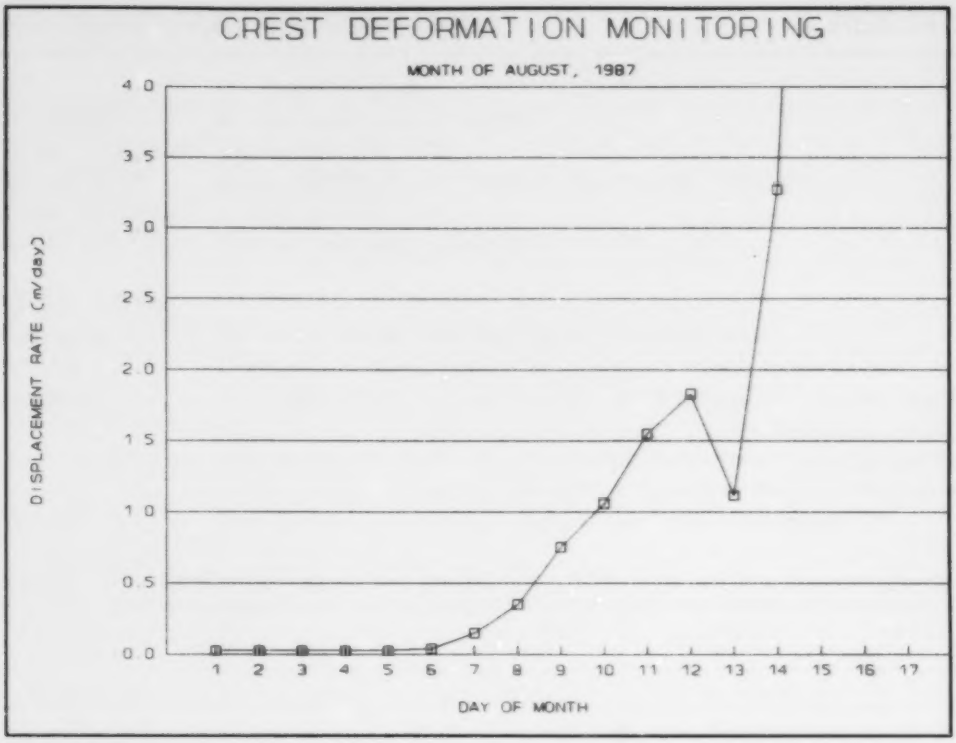
DISCUSSION

Dump toe advanced over frozen soils during winter construction forming and insulating a continuous impermeable boundary. Groundwater recharge was assumed to be high given the amount of precipitation recorded, resulting in increased foundation pore pressure below the frozen zone. The initial stage of the failure originated in the toe by this uplift mechanism causing basal sliding at, or just below, the foundation contact. A bulge was observed on the slope prior to failure indicating high stress conditions being transferred to the toe.

The subsequent stage included failure through the dump material upon loss of toe support, in fact failure planes had probably already been established within the dump causing the transfer of stress to the toe and the observed slope bulge. The extent of this type of flow is related to the degree of saturation and fines content of the dump material. The backscarp was observed to be 60 m behind the crest and had a series of cracks up to 3 m in depth.

Another factor influencing the instability was the slight promontory developed in the area of the failure. Development of dump crests in this manner provides limited confinement for the advancing toe.




CREST DEFORMATION MONITORING
MONTH OF AUGUST, 1987
DISPLACEMENT RATE (mm/day)
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17
DAY OF MONTH

MINE DUMP FAILURE SUMMARY — RECORD NO. 7

MINE: C - Open pit coal
DUMP NAME: A - Active at time of failure.
DATE OF FAILURE: September 10, 1987
DUMP HEIGHT: 205 m (crest at elev. 1980 m, toe at elev. 1775 m)
FAILURE VOLUME: 1 x 10^6 m^3
RUNOUT DIST.: 190 m (average runout slope = 11°)

GENERAL DATA:

Topography 11° slope at toe, concave downward in profile
Geometry Unconfined sidehill fill, no 3D wedging effect, linear in plan.
Foundation One metre thick blanket of colluvial silty sand and gravel overlying dense till. An undetermined quantity of poor quality, saturated overburden soil was deposited on the foundation slope sometime prior to the construction of the dump, saturated debris from previous failures also present.
Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH $\phi'(^\circ)$, C'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	<#200
SILTSTONE (50)	110	37°, 0	LA = 34 / SD = 98	70	1
SANDSTONE (25)	130		LA = 34 / SD = 98		
MUDSTONE (25)	55		LOW		

DESIGN ASSUMPTIONS:

Material Strengths Dump ϕ'=37°, c'=0; Foundation ϕ'=33°, c'=0
Piezometric Assumptions Excess pore water pressure dissipation required.
Method of Stability Calculation Basal Sliding analysis
Design Safety Factor ~1.0 (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
>200 m = 200	1-50 Mm^3 = 50	37° = 100	10-25° = 50	100	200
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
100	200	100	100	0	**1200**/1800

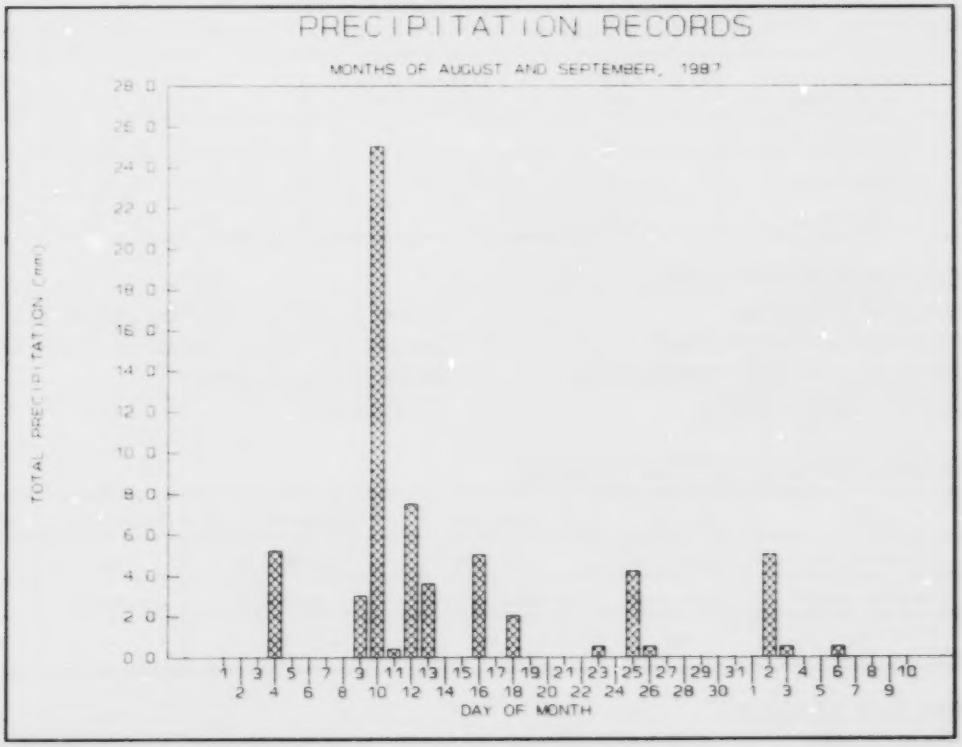
FAILURE DETAILS:

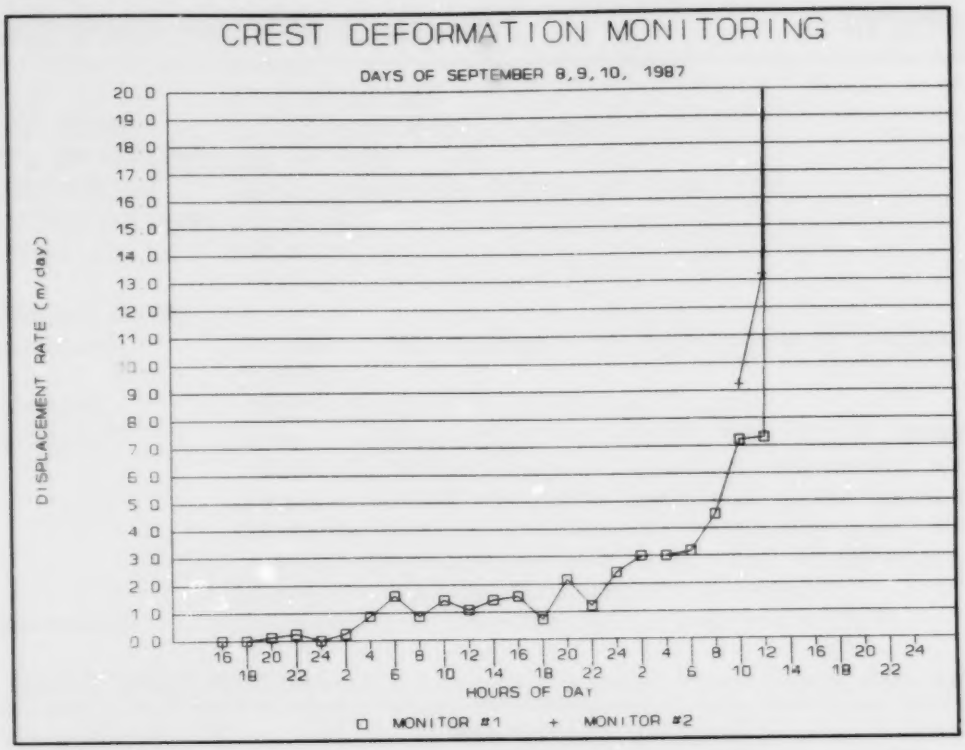
Loading rate Loading in excess of 150 BCM/m/day based on estimate of volume placed in August 15, 1987 failure void.
Monitoring Movement rates exceeded 600 mm/day 2 days prior, and exceeded 1200 mm/day for 20 hours prior to failure.
Climate Data Precipitation not considered a factor of instability.
Indicated Mode Non-circular rotational slump
Indicated Cause Pore pressure generation associated with rapid loading of previous failure debris from the August 15, 1987 failure and in the saturated surficial soils.

DISCUSSION

Instability occurred in the vicinity of the August 15, 1987 failure, however, this failure was more extensive in size and included dump material not previously involved. The backscarp was approximately 25 m high and up to 75 m behind the crest. The failure is associated with rapid loading of failure debris and saturated soils of the foundation. Part of the debris lobe from the August event provided toe support for the recently placed material. Observations by eyewitnesses record that much ravelling of the August failure debris coincided with crest settlement of the new dump material. Shortly thereafter the entire face slumped.

The failure occurred relatively rapidly (estimated to be 25 km/h by eye witnesses), probably due to the degree of saturation of the foundation soils, previous slide debris, and dump materials. Very saturated "muddy" debris flowed down slope and impacted on the debris lobe from the January 30, 1984 failure. After this the flow moved slowly downslope in a creeping manner for an additional 50 m.





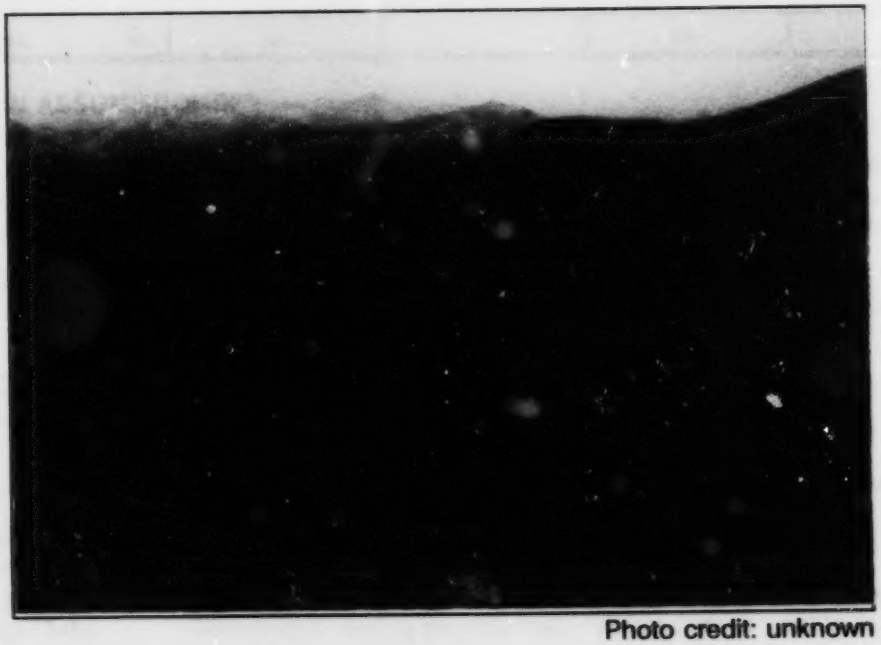


Photo credit: unknown

Photograph 1: Record 7 dump failure.

MINE DUMP FAILURE SUMMARY — RECORD NO. 8

MINE: C - Open pit coal
DUMP NAME: B - Not active at time of failure.
DATE OF FAILURE: July 16, 1986
DUMP HEIGHT: 200 m (crest at elev. 1970 m, toe at elev. 1770 m)
FAILURE VOLUME: 4×10^6 m^3
RUNOUT DIST.: 350 m

GENERAL DATA:

Topography Toe slope = 15°; mid slope = 22°; crest slope = 30°; concave downward in profile

Geometry Unconfined sidehill fill; convex shape in plan

Foundation Veneer of organic topsoil and previous mine rock fill material overlying colluvial silty sands and gravels, rock fragments, cobbles, and boulders. Blanket of dense to very dense glacial till on gentler slopes all overlying soft marine shales. Some pockets of soft weak clay, up to 1 m in thickness to be selectively removed prior to dumping. No significant foundation seepage locations during investigation observed.

Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH $\phi'(^\circ)$,c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	PARTICLE SIZE (%) <#200
SILTSTONE (50)	110	37°, 0	LA = 34 / SD = 98	70	1
SANDSTONE (25)	130		LA = 34 / SD = 98		
MUDSTONE (25)	55		LOW		

DESIGN ASSUMPTIONS:

Material Strengths Dump $\phi'=37°$, $c'=0$; Foundation $\phi'=35°$, $c'=0$

Piezometric Assumptions Drained, rock drain constructed in gully

Method of Stability Calculation Basal sliding analysis

Design Safety Factor 1.3 to 1.5 depending on slip surface (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
100-200m = 100	>50Mm³ = 100	37° = 100	10-25° = 50	100	200
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
100	200	200	0	0	**1150**/1800

FAILURE DETAILS:

Loading rate Dump not active during shutdown, no loading for 3 weeks prior to failure.

Monitoring Operating limit of 600 mm/day exceeded only twice for previous month

Climate Data Severe cold during previous fall, rain for 3 days prior to failure.

Indicated Mode Toe failure causing loss of support for dump mass above.

Indicated Cause Foundation frozen during construction forming an impermeable boundary below dump toe; increase in foundation pore pressures due to frozen boundary and spring melt causing groundwater recharge.

DISCUSSION

A large portion of the dump was advanced during winter over frozen foundation conditions due to the extreme cold of the previous fall. The dump material would effectively act as an insulator, preventing the frozen ground from thawing well into the summer. Coincidentally, spring melt water and precipitation caused groundwater recharge. As the groundwater was prevented from draining through the frozen layer hydrostatic uplift forces would create a reduction in shear strength until failure. This is the initial mechanism causing toe failure and leading to progressive failure.

The second stage of failure occurred due to loss of support from the failure of the toe.

New stresses develop and failure can occur along a surface where the material shear strength is overcome, often along a plane of weakness if one exists, or in a rotational manner if the material is relatively homogeneous. The second stage failure in this event may have included both mechanisms through the failure plane.

The failure was characterized by a scarp 100 m behind crest, and rate of movement of 1-2 m/s down slope as observed by eyewitnesses. The debris was contained by a toe dike previously constructed to protect nearby mine facilities.

Observations made during a review of relevant documentation regarding the failure include the possibility of a spring seepage zone existing in the foundation at approximately mid height. It was postulated at the time that folded sedimentary structures in the bedrock formation were providing a conduit for groundwater recharge and discharge specifically at the mid dump height location within the foundation. Features such as these will directly influence stability and should be considered during site investigation and design.

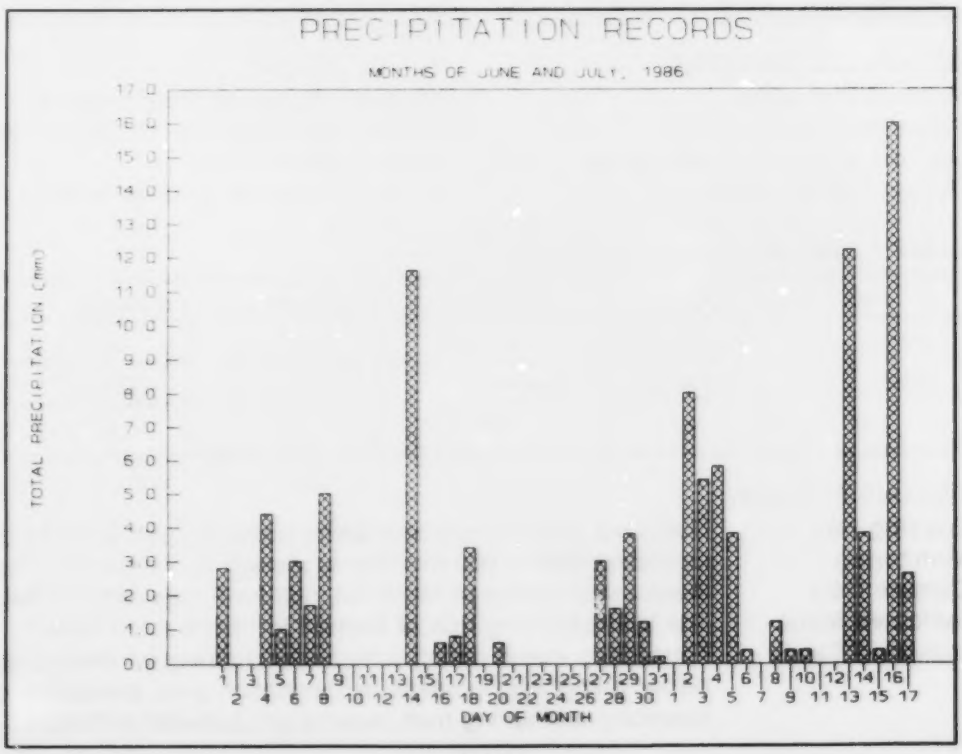


Photo credit: unknown

Photograph 1: Record 8 dump failure and runout.

Photo credit: D.B. Campbell

Photograph 2: Record 8 dump failure.

MINE DUMP FAILURE SUMMARY — RECORD NO. 9

MINE: C - Open pit coal
DUMP NAME: B - Active at time of failure.
DATE OF FAILURE: October 21-24, 1987
DUMP HEIGHT: 270 m (crest at elev. 1970 m, toe at elev. 1700 m)
FAILURE VOLUME: 1×10^6 m^3
RUNOUT DIST.: Runout contained by toe dike, lateral spreading

GENERAL DATA:

Topography Toe slope = 15°; mid slope = 22°; crest slope = 30°; concave downward in profile.

Geometry Unconfined sidehill fill, no 3D wedging effect

Foundation Veneer of organic soil and mine rock fill material overlying colluvial silty sands and gravels, rock fragments, cobbles, and boulders. Blanket of dense to very dense glacial till on gentler slopes all overlying soft marine shales. Some pockets of soft weak clay, up to 1 m in thickness. No significant foundation seepage locations observed during investigation.

Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH $\phi'(^\circ)$,C'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	PARTICLE SIZE (%) <#200
SILTSTONE (50)	110	37°, 0	LA = 34 / SD = 98	70	1
SANDSTONE (25)	130		LA = 34 / SD = 98		
MUDSTONE (25)	55		LOW		

DESIGN ASSUMPTIONS:

Material Strengths Dump $\phi'=37°$, $c'=0$; Foundation $\phi'=35°$,$c'=0$
Piezometric Assumptions Drained (see legend)
Method of Stability Calculation Basal Sliding analysis
Design Safety Factor 1.3 to 1.5 depending on slip surface

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
>200m = 200	>50Mm³ = 100	37° = 100	10-25° = 50	100	200
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
200	200	200	100	0	**1450**/1800

FAILURE DETAILS:

Loading rate Loading rates had increased and although considered a factor in the instability, specific rates were not reported.

Monitoring Previously operated on maximum 600 mm/day, approval to operate at 1200 mm/d given on October 19, 1990.

Climate Data Precipitation not considered a factor of instability.

Indicated Mode Yielding toe/planar.

Indicated Cause Pore pressure response in foundation and 1986 failure debris, induced by strain rate and increased rate of loading.

DISCUSSION

The failure originated in the vicinity of the 1986 event, and involved the debris from the 1986 event at the foundation contact. The mode of failure includes a progressive instability which probably initiated at the toe, and later affected the unsupported mass of the dump. Test pit investigations through the shear zone indicate saturated soil conditions for a depth of 3.5 m.

The dump was operated at a maximum allowable crest deformation rate of 600 mm/day, and was approved to operate at 1200 mm/day (dump short and push) on October 19, 1987. Loading rate data were not reported, however it can be assumed that loading rates were greater than previously placed, given the higher allowable monitoring rate. Higher loading rates and the inherent decrease in the time allowed for pore pressure dissipation were major factors in the instability. Higher loading rates may also contribute to deformation of the foundation material causing strain induced pore pressure response as loose saturated soils undergo shear strains.

Other factors contributing to instability include poor quality saturated foundation soils, poor quality dump material, and previous failure debris. In addition, observations made during a review of relevant documentation regarding the 1986 failure include the possibility of a spring seepage zone existing in the foundation at approximately mid height. It is postulated that folded sedimentary structures in the bedrock formation were providing a conduit for groundwater recharge and discharge specifically at the mid dump height location within the foundation. Seepage features such as these will directly influence stability and should be considered during site investigation and design.

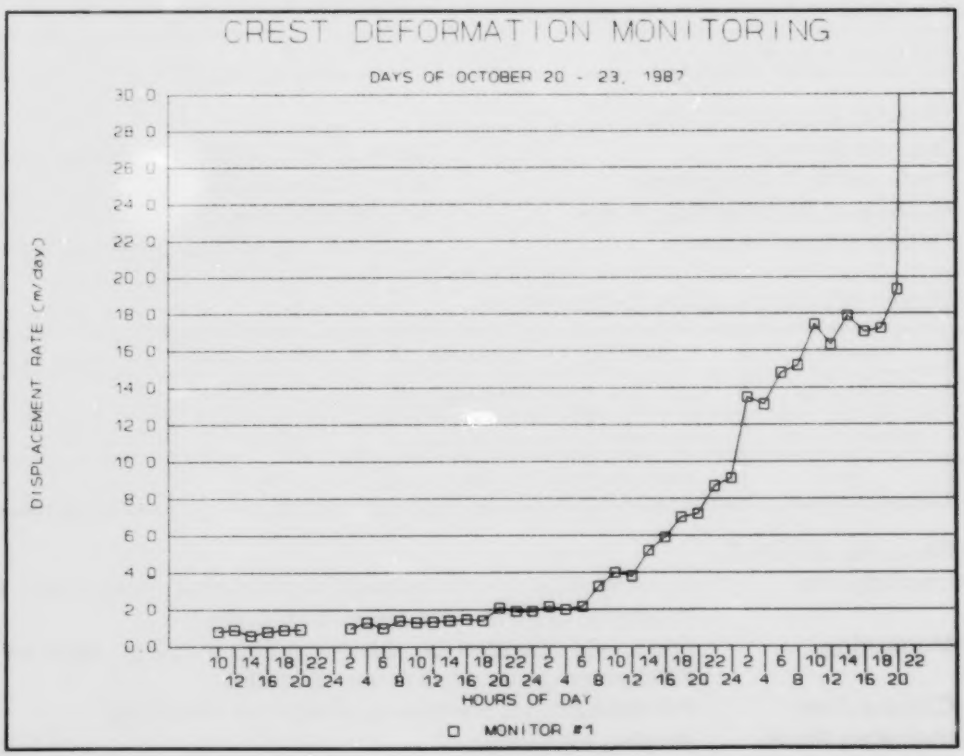


Photo credit: unknown

Photograph 1: Record 9 dump failure.

MINE DUMP FAILURE SUMMARY — RECORD NO. 10

MINE: C - Open pit coal
DUMP NAME: C - Active at time of failure.
DATE OF FAILURE: March 6, 1991
DUMP HEIGHT: 300 m (crest elev. 2285 m, toe at elev. 1980 m)
VOLUME: 30 x 10^6 m^3
RUNOUT DIST.: N/A, failure caused uplift and thickening of previous failure debris at toe.

GENERAL DATA:

Topography Toe slope=15-20°; mid slope=30°; crest slope=40°, minor drainage gullies downslope; concave downward in profile

Geometry Unconfined sidehill fill (at time of failure), no 3D wedging effect

Foundation Veneer of colluvial silty sands and gravels on steep slopes, up to 1 m thick on lessor slopes, overlying folded sedimentary units: sandstone, shale, mudstone, and coal. Varying thickness of dense glacial till may be present on bedrock on flatter slopes. Debris from previous failure events over much of lower slopes and in toe areas.

Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests

DUMP ROCK TYPE (% BY VOLUME)		UCS (MPa)	ESTIMATED STRENGTH $\phi'(°)$, c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	<#200
SILTSTONE	(50)	110	37°, 0	LA = 34 / SD = 98	70	1
SANDSTONE	(25)	130		LA = 34 / SD = 98		
MUDSTONE	(25)	55		LOW		

DESIGN ASSUMPTIONS

Material Strengths Dump ϕ'=37°, c'=0; Foundation ϕ'=33°, c'=0

Piezometric Assumptions Drained (see legend)

Method of Stability Calculation: Double Wedge

Design Safety Factor 1.53 ultimate dump (static), ~1.0 for intermediate stages

DUMP STABILITY RATING SCHEME

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
>200m = 200	>50Mm³ = 100	37° = 100	25-32° = 100	100	200
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
100	200	100	100	0	**1300**/1800

FAILURE DETAILS:

Loading Rate Average 35,000 BCM/day (+250 BCM/m crest/day).

Monitoring Crest deformations to 10,000 mm/day prior to closure.

Climate Data Climate data not considered a factor of instability.

Indicated Mode Double wedge, or yielding foundation soils at the toe foundation and loss of support for mass above permitting basal sliding along foundation.

Indicated Cause Generation of pore pressures within the toe foundation contact zone, due to rapid redistribution of stresses within the dump, or strain induced pore pressure of the foundation.

DISCUSSION

Large strains were observed in the dump for several years. The dump was operated based on monitoring guidelines and, given the foundation topography, unconfined geometry, and loading rate, was recognized as being actively "creeping" and "settling". The dump was under construction in a staged method at time of failure, and failure occurred across the upper and lower stages.

The failure can be attributed to toe yielding brought about by an increase in foundation pore pressures at the toe, causing a loss of support for the mass above. The catalyst for the increase in pore pressure and resulting progressive failure may be the rapid redistribution of stresses within the dump itself or strain induced pore pressures.

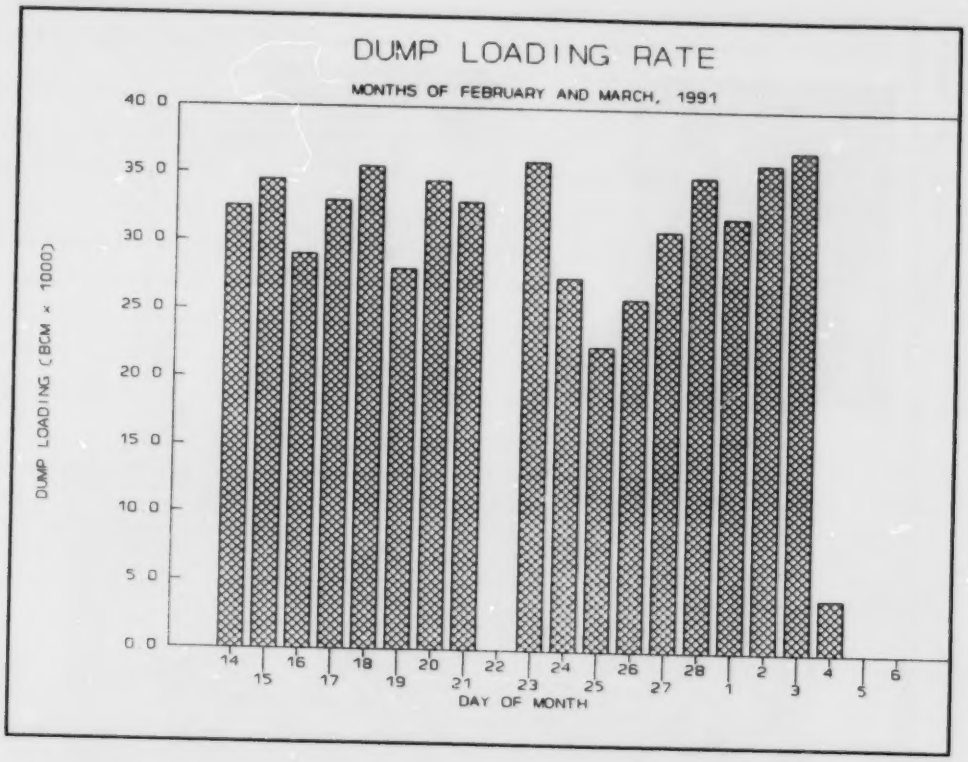
Substantial debris from previous failures blanketed the valley bottom below at the dump toe. This material was observed to be increasing in elevation for the past 4 to 5 years, and was attributed to dump creep movements. As the debris increased in elevation, the capacity as a toe buttress increased, probably retarding toe movement over time. Since the increase in load was relatively slow, adequate pore pressure dissipation was achieved from the foundation. Concurrent with this, potential failure planes associated with large creep had developed in the large dump, along which the material strength may have been reduced due to the incurred movement. In addition, normal loading of the dump crest continued, promoting further movement along these planes.

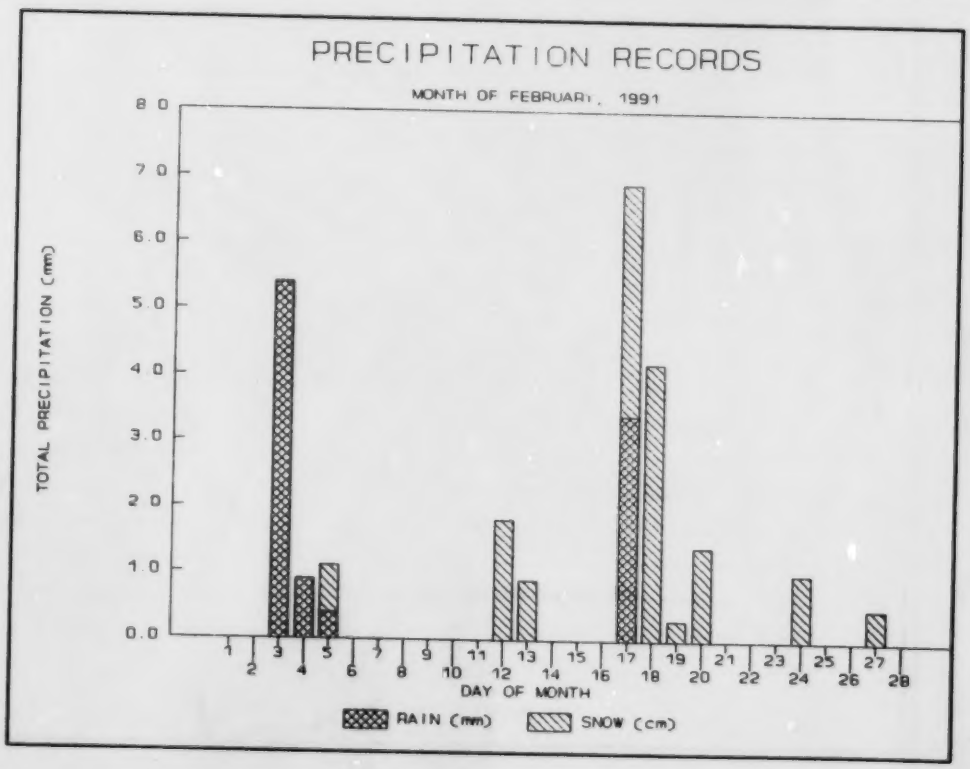
At some time 3 to 4 days before the failure a combination of increased toe buttressing and reduced shear strength along potential failure planes caused a rapid redistribution of stresses within the dump. As creep movements were arrested at the toe continued movement and deformation of the dump (along shear planes) caused prominent face bulging. Two days prior to failure the platform had dropped 15-20 m for a distance of 200 m from the crest, and a slight bulge was observed. One day prior to failure the vertical displacement was 30 m across the same area with much more pronounced bulging, and just prior to failure the crest had dropped 50-60 m and had developed a large bulge on the face.

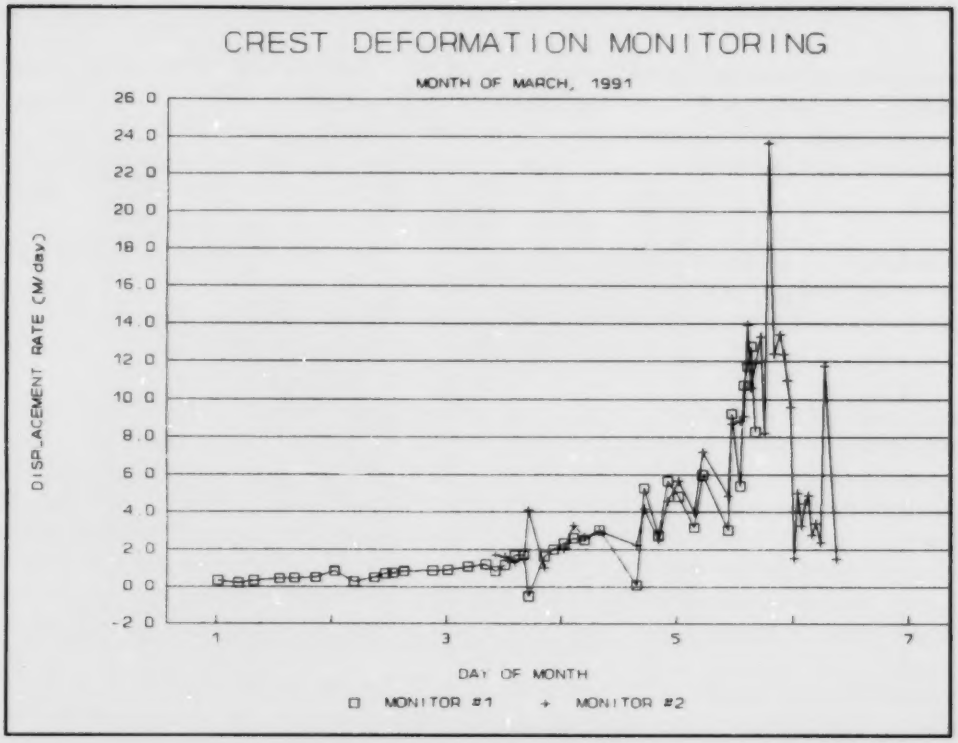
No large toe deformations were observed to coincide with these movements, indicating that movement at the toe may have been arrested. The redistribution of loads over this short period effectively increased pore pressures within the foundation very rapidly. It is estimated that the changing load over the period just prior to the failure produced an "equivalent" loading rate in excess of 350 BCM/m/day two days prior, 750 BCM/m/day one day prior, and 2200 BCM/m/day just before failure. Loading rates in excess of 200 BCM/m/day are considered to be sufficient to generate foundation pore pressures greater than the rate of dissipation, at similar sites and under similar conditions.

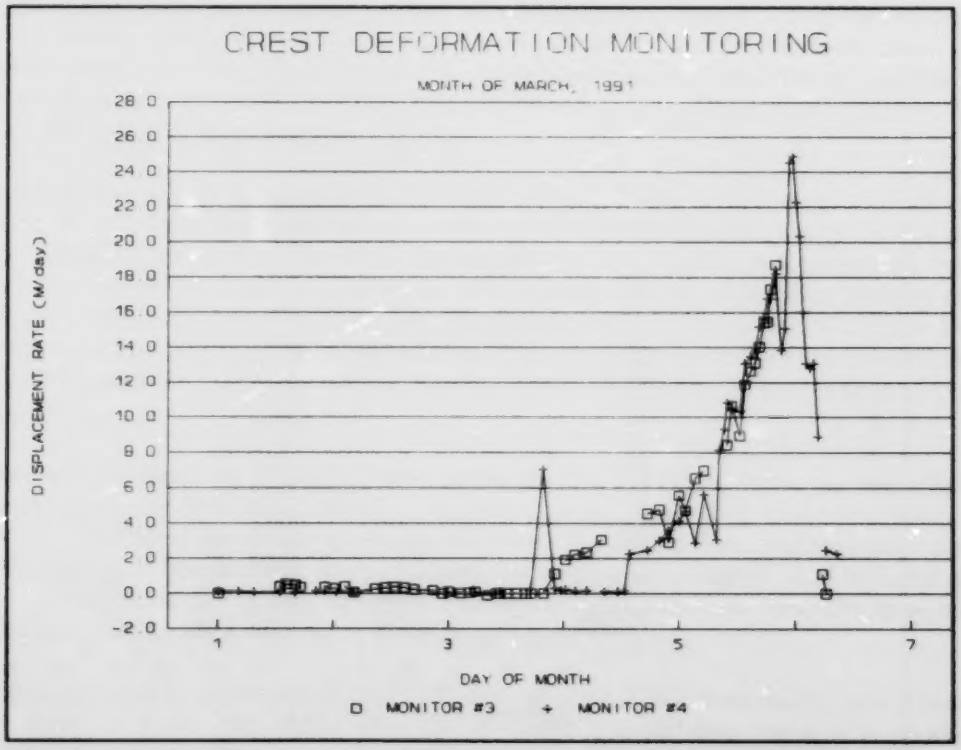
Once failure was initiated, the previous debris at the toe and the failing dump toe material were observed to move out in a rapid fluid-like rippling manner, indicating that foundation pore pressures had increased over a large area by this time. The total failure time was estimated to be 5 to 10 minutes, in keeping with pore pressure generation type failures, and reduced shear strengths to lower value along failure planes. The remaining dump mass failed in large blocks or wedges, consistent with a secondary basal mechanism.

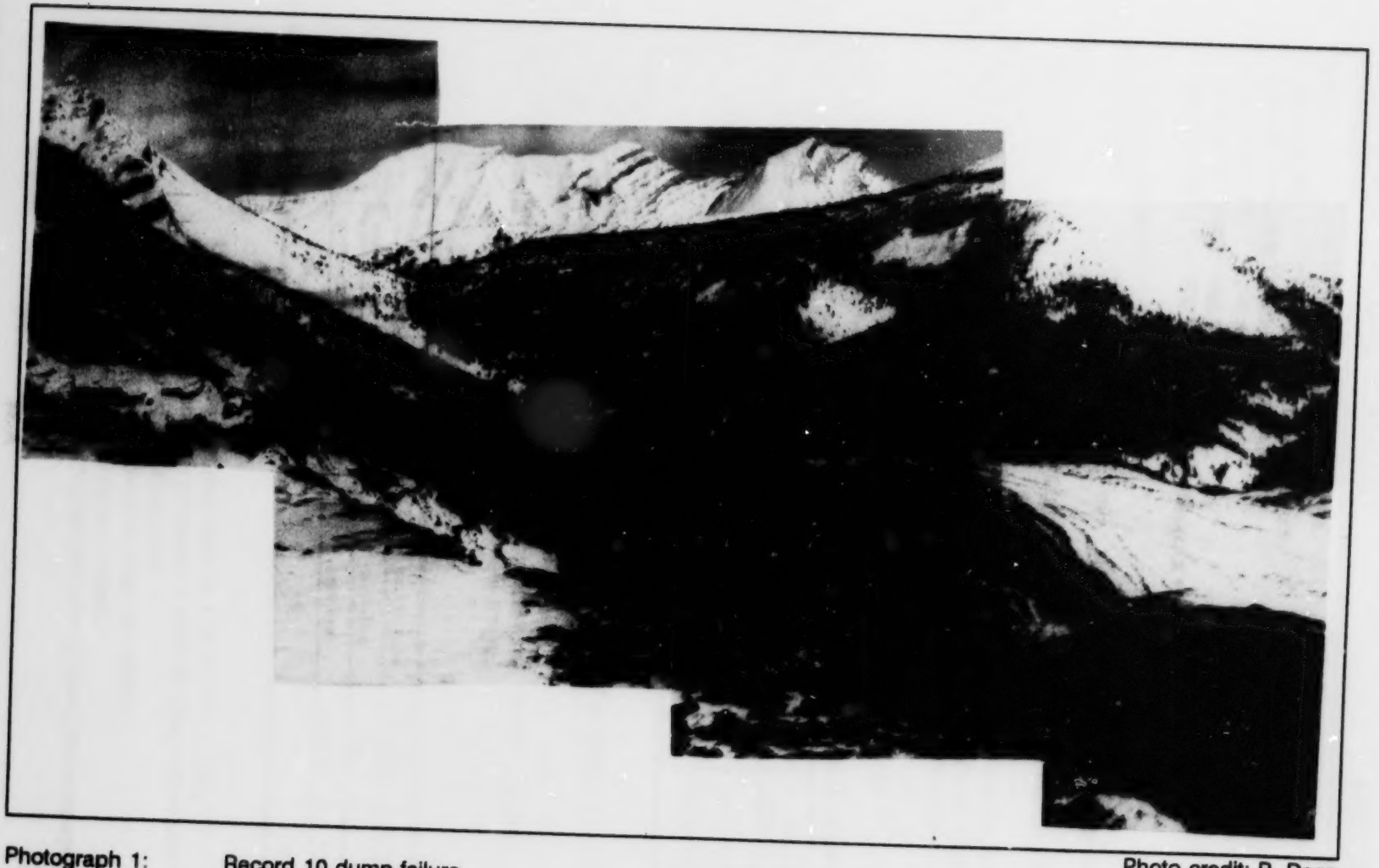
Groundwater recharge by precipitation and meltwater was influential in elevating pore pressures within the dump and reducing shear strength on failure planes, and perhaps in producing foundation seepage pressures.


DUMP LOADING RATE
MONTHS OF FEBRUARY AND MARCH, 1991
DUMP LOADING (BCM x 1000)
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 1 2 3 4 5 6
DAY OF MONTH


PRECIPITATION RECORDS
MONTH OF FEBRUARY, 1991
TOTAL PRECIPITATION (mm)
8.0
7.0
6.0
5.0
4.0
3.0
2.0
1.0
0.0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28
DAY OF MONTH
RAIN (mm)
SNOW (cm)


CREST DEFORMATION MONITORING
MONTH OF MARCH, 1991
DISPLACEMENT RATE (M/day)
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
1
3
5
7
DAY OF MONTH
MONITOR #1
MONITOR #2


CREST DEFORMATION MONITORING
MONTH OF MARCH, 1991
DISPLACEMENT RATE (M/day)
28.0
26.0
24.0
22.0
20.0
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
-2.0
1
3
5
7
DAY OF MONTH
MONITOR #3
MONITOR #4



Photograph 1: Record 10 dump failure.

Photo credit: R. Dean

MINE DUMP FAILURE SUMMARY — RECORD NO. 11

MINE: C - Open pit coal
DUMP NAME: C - Active at time of failure.
DATE OF FAILURE: September 21, 1984
DUMP HEIGHT: 215 m
FAILURE VOLUME: 400,000 m^3
RUNOUT DIST.: 900 m (average 15-20° runout slope)

GENERAL DATA:

Topography Toe slope=20-30°; mid slope=38°; crest slope=38-40°; concave downward in profile

Geometry Unconfined sidehill fill (at time of failure), minor 3D wedging effect in small gully.

Foundation Veneer of colluvial silty sands and gravels on steep slopes, up to 1 m thick on lesser slopes, overlying folded sedimentary units of sandstone, shale, mudstone, and coal. Varying thickness of dense glacial till may be present on bedrock on flatter slopes.

Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)		UCS (MPa)	ESTIMATED STRENGTH $\phi'(^\circ)$, c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	<#200
SILTSTONE	(50)	110	37°, 0	LA = 34 / SD = 98	70	1
SANDSTONE	(25)	130		LA = 34 / SD = 98		
MUDSTONE	(25)	55		LOW		

DESIGN ASSUMPTIONS

Material Strengths Dump $\phi'=37°$, $c'=0$; Foundation $\phi'=33°$, $c'=0$

Piezometric Assumptions Drained (see legend)

Method of Stability Calculation: Double Wedge

Design Safety Factor 1.53 for ultimate dump (static), ~1.0 for intermediate stages

DUMP STABILITY RATING SCHEME

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
>200m = 200	>50Mm³ = 100	37° = 100	25-32° = 100	100	200
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
100	200	200	100	0	1400/1800

FAILURE DETAILS:

Loading rate Loading rates not reported, may be a factor of instability.

Monitoring Crest deformation rates in excess of 1400 mm/day 4 days prior to failure, dumping stopped at 600 mm/day

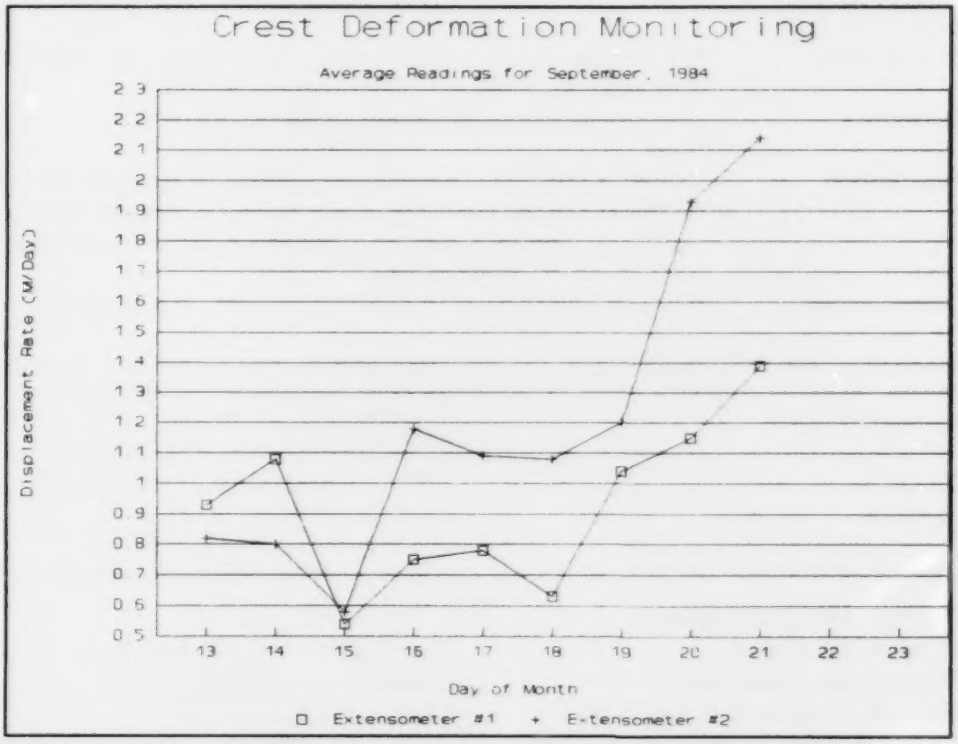
Climate Data Precipitation not considered a factor of instability.

Indicated Mode Basal sliding along foundation contact.

Indicated Cause High strains due to loading rate (unknown); foundation seepage pressures in gully.

DISCUSSION

The low strength of the colluvial soils at foundation contact may have contributed to the basal failure of the dump material. The failure appeared to be primarily related to steep foundation topography and loading rate. However, seepage pressures may have existed in the dump foundation, within the drainage course previously defined by a small gully. If drainage within surficial soils cannot occur, seepage pressures can become elevated and reduce the shear strength of the surficial soils, or may raise the phreatic surface in the dump material.



MINE DUMP FAILURE SUMMARY — RECORD NO. 12

MINE: C - Open pit coal
DUMP NAME: C - Active at time of failure.
DATE OF FAILURE: September 16, 1985
DUMP HEIGHT: 215 m
FAILURE VOLUME: 225,000 m^3
RUNOUT DIST.: 900 m (average 15-20° runout slope)

GENERAL DATA:

Topography Toe slope=20-30°; mid slope=38°; crest slope=38-40°; concave downward in profile

Geometry Unconfined sidehill fill (at time of failure), minor 3D wedging effect in small gully.

Foundation Veneer of colluvial silty sands and gravels on steep slopes, up to 1 m thick on lessor slopes, overlying folded sedimentary units: sandstone, shale, mudstone, and coal. Varying thickness of dense glacial till may be present on bedrock on flatter slopes.

Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)		UCS (MPa)	ESTIMATED STRENGTH $\phi'(°)$, c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	PARTICLE SIZE (%) <#200
SILTSTONE	(50)	110	37°, 0	LA = 34 / SD = 98	70	1
SANDSTONE	(25)	130		LA = 34 / SD = 98		
MUDSTONE	(25)	55		LOW		

DESIGN ASSUMPTIONS

Material Strengths Dump ϕ'=37°, c'=0; Foundation ϕ'=33°, c'=0

Piezometric Assumptions Drained (see legend)

Method of Stability Calculation: Double Wedge

Design Safety Factor 1.53 Ultimate dump (static), ~1.0 for Intermediate stages

DUMP STABILITY RATING SCHEME

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
>200m = 200	>50Mm³ = 100	37° = 100	25-32° = 100	100	200
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
100	200	200	100	0	1400/1800

FAILURE DETAILS:

Loading rate Loading rates not reported, but may be an factor of instability.

Monitoring Crest deformation rates in excess of 1400 mm/day 4 days prior to failure, dumping stopped at 600 mm/day

Climate Data Precipitation not considered a factor of instability.

Indicated Mode Basal sliding along foundation contact.

Indicated Cause High strains due to loading rate (unknown); foundation seepage pressures in gully.

DISCUSSION

The low strength of the colluvial soils at foundation contact may have contributed to the basal failure of the dump material. The failure appeared to be primarily related to steep foundation topography and loading rate. However, seepage pressures may have existed in the dump foundation, within the drainage course previously defined by a small gully. If drainage within surficial soils cannot occur, seepage pressures can become elevated and reduce the shear strength of the surficial soils, or may raise the phreatic surface in the dump material.

MINE DUMP FAILURE SUMMARY — RECORD NO. 13

MINE: C - Open pit coal
DUMP NAME: C - Active at time of failure.
DATE OF FAILURE: October 9, 1988
DUMP HEIGHT: 350 m
FAILURE VOLUME: 8 x 10^6 m^3
RUNOUT DIST.: N/A

GENERAL DATA:

Topography Toe slope=15-20°; mid slope=30°; crest slope=40°, minor drainage gullies downslope; concave downward in profile

Geometry Unconfined sidehill fill (at time of failure), no 3D wedging effect

Foundation Veneer of colluvial silty sands and gravels on steep slopes, up to 1 m thick on lessor slopes, overlying folded sedimentary units of sandstone, shale, mudstone, and coal. Varying thickness of dense glacial till may be present on bedrock on flatter slopes. Previous failure debris present at toe.

Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)		UCS (MPa)	ESTIMATED STRENGTH $\phi'(°)$, $c'(kPa)$	DURABILITY (%)	PARTICLE SIZE (%) >300mm	<#200
SILTSTONE	(50)	110	37°, 0	LA = 34 / SD = 98	70	1
SANDSTONE	(25)	130		LA = 34 / SD = 98		
MUDSTONE	(25)	55		LOW		

DESIGN ASSUMPTIONS

Material Strengths Dump ϕ'=37°, c'=0; Foundation ϕ'=33°, c'=0

Piezometric Assumptions Drained

Method of Stability Calculation: Double Wedge

Design Safety Factor 1.53 ultimate dump (static), ~1.0 for intermediate stages

DUMP STABILITY RATING SCHEME

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
>200m = 200	>50Mm³ = 100	37° = 100	25-32° = 100	100	100
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
100	200	100	100	0	**1200**/1800

FAILURE DETAILS:

Loading rate Typical loading rates of 20 BCM/m/day reported prior to failure.

Monitoring Movement exceeded 1,200 mm/day (maximum allowable for dumping) 10 days prior, and accelerated to 17,000 mm/day immediately prior to failure.

Climate Data Climate data not considered a factor of instability.

Indicated Mode Double wedge, or yielding foundation soils at the toe foundation and loss of support for mass above permitting basal sliding along foundation.

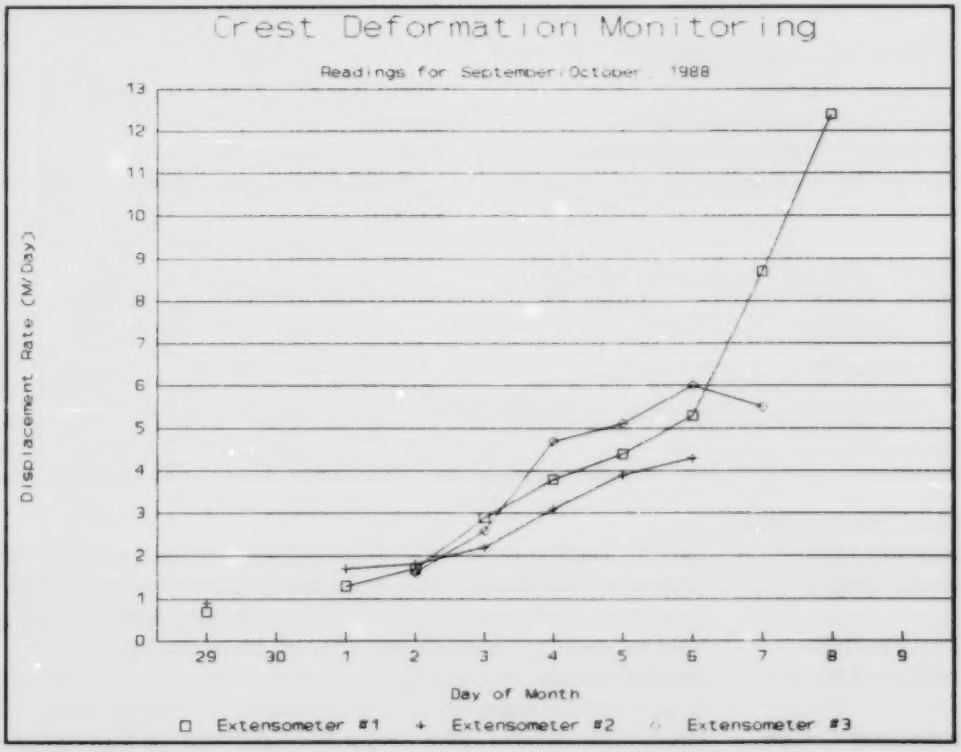
Indicated Cause Generation of pore water pressures within the toe foundation contact zone, due to rapid redistribution of stresses within the dump.

DISCUSSION

The failed dump was under construction in a staged method with the failure occurring across both the upper and lower stages. Monitoring was not being performed on the upper stage since that area had been inactive for some time. The monitoring data presented represent readings of the lower stage crest. The area of failure included a portion of the dump constructed in a promontory from the remainder of the dump, and therefore had little confinement.

The failure can be attributed to toe failure brought about by an increase in foundation pore pressures at the toe, causing a loss of support for the mass above. The catalyst for the increase in pore pressure and resulting overall failure is the redistribution of stresses within the dump itself. This may have been caused by a combination of the promontory developed in the direction of dump construction, and steep topography for the upper part of the dump. A redistribution of stresses can be realized by the large deformations which were observed on the dump approximately 8 days prior to failure; development of a 60 to 70 m vertical "step" across the failure plane, and the concurrent development of a slope face bulge. No discernable deformations were evident at the toe region during this time, as observed from the crest, such that the toe material was being subject to increased loading without major deformation, inferring an direct increase load on the foundation materials.

Once the toe yielded the remainder of the dump failed progressively until a stable configuration was reached. The failed material moved relatively slowly (1-2 m/s) bulldozing and covering failure debris covering the valley bottom from previous events. This event significantly increased the thickness of the valley bottom debris. No significant seepage was observed exiting the dump or the debris prior to, or after the failure.



MINE DUMP FAILURE SUMMARY — RECORD NO. 14

MINE: C - Open pit coal
DUMP NAME: D - Roadway fill access to dump
DATE OF FAILURE: July 7, 1990
DUMP HEIGHT: Roadway height varies, maximum thickness = 130 m
FAILURE VOLUME: 300,000 m^3
RUNOUT DIST.: Not reported

GENERAL DATA:

Topography Maximum slope 35°
Geometry Roadway fill in confined gully
Foundation Veneer of colluvial silty sands and gravels on steep slopes, up to 0.6 m thick on lessor slopes, particles range from silt size to angular cobbles, many with tabular dimensions. Underlying folded sedimentary units: sandstone, shale, mudstone, and coal. Toe advance on frozen ground.
Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH $\phi'(^\circ)$, c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	<#200
SILTSTONE (50)	110	37°, 0	LA = 34 / SD = 98	70	1
SANDSTONE (25)	130		LA = 34 / SD = 98		
MUDSTONE (25)	55		LOW		

DESIGN ASSUMPTIONS:

Material Strengths Roadway fill $\phi'=37°$, c'=0; Foundation $\phi'=34°$, c'=0
Piezometric Assumptions Drained (see legend)
Method of Stability Calculation Double Wedge, Sarma
Design Safety Factor 1.16, 1.18

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
100-200m = 100	1-50Mm³ = 50	37° = 100	25-32° = 100	100	100
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
100	200	300	200	0	**1250/1800**

FAILURE DETAILS:

Loading rate Loading rate not recorded during roadway construction, entire volume of 300,000 m^3 placed during February and March, 1990 (est. 50 BCM/m/day).
Monitoring Monitor established after considerable acceleration.
Climate Data Unusually wet spring with heavy rainfall on day preceding failure.
Indicated Mode Basal sliding
Indicated Cause High pore pressure due to excess precipitation and runoff (initially under frozen foundation, and later in dump material); loading failure with excess material to bring up roadway grade after initial slump.

DISCUSSION

The roadway material was placed during winter months, effectively covering frozen foundation soils. The embankment remained stable up to the time of the failure, probably insulating the frozen foundation. During the wet spring groundwater recharge in the foundation caused increased seepage pressures behind the frozen mantle at the fill/foundation contact.

Prior to July 7, 1990, the roadway was observed to settle appreciably, and subsequent to that 2 lifts (assumed 5-10 m) of new material were placed to bring up the grade. The first movement probably relieved foundation seepage pressures by disturbing the frozen foundation, allowing inflow of water through the foundation which suddenly saturated the material and elevated pore pressures at the foundation contact. Continued seepage through the foundation, the addition of 2 lifts of new material at the road level, and runoff from the July 6, 1990 precipitation, probably all combined to cause the failure.

MINE DUMP FAILURE SUMMARY — RECORD NO. 15

MINE: C - Open pit coal
DUMP NAME: D - Active at time of failure.
DATE OF FAILURE: October 26, 1989
DUMP HEIGHT: 435 m (crest at elev. 2195 m, toe at 1760 m)
FAILURE VOLUME: 2.5×10^6 m^3
RUNOUT DIST.: 1200 M (abutted opposite valley wall)

GENERAL DATA

Topography Toe slope= 27°; mid slope=25-30°; crest slope = 30°; concave shape in profile.

Geometry Gully confined valley fill; concave shape in plan.

Foundation Veneer of colluvial silty sands and gravels on steep slopes, up to 0.6 m thick on lessor slopes, particles range from silt size to angular cobbles, many with tabular dimensions. Underlying folded sedimentary units of sandstone, shale, mudstone, and coal. Toe advance on frozen ground.

Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH $\phi'(^\circ)$, c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	<#200
SILTSTONE (50)	110	37°, 0	LA = 34 / SD = 98	70	1
SANDSTONE (25)	130		LA = 34 / SD = 98		
MUDSTONE (25)	55		LOW		

DESIGN ASSUMPTIONS:

Material Strengths Dump ϕ'=38°, c'=0; Foundation ϕ'=35-38°, c'=0

Piezometric Assumptions Drained

Method of Stability Calculation Double Wedge, 3 Dimensional wedging analysis

Design Safety Factor 1.04-1.16 (with varied friction at foundation contact)

DUMP STABILITY RATING SCHEME

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
>200m = 200	1-50Mm^3 = 50	37° = 100	25-32° = 100	50	100
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
100	200	100	200	0	1200/1800

FAILURE DETAILS:

Loading Rate Average loading for 3 months prior to failure = 171 BCM/m/day. The loading rate was also frequently in excess of 200 BCM/m/day.

Monitoring Peak rates of 2500 mm/d for 4 months prior, generally less than 1000 mm/d for month, and 6000 mm/d for day prior to failure.

Climate Data Precipitation not considered a factor of instability.

Indicated Mode ielding toe/ basal along foundation contact.

Indicated Cause High deformation leading to strain softening along foundation contact; overestimation of foundation shear strengths and three dimensional confining effects; high loading rates during winter months and toe advance over frozen ground.

DISCUSSION

The failure occurred rapidly and attained a velocity in excess of 100 km/h when debris reached the valley floor. Prior to failure and during a period of pronounced crest settlement the toe was inspected and reported as being well supported.

Back analysis indicated a lower strength for foundation soils than originally estimated and a factor of safety very close to unity for the configuration at failure. The specific cause of the instability is not clear but can be attributed to the following factors, since the overall factor of safety for stability was low:

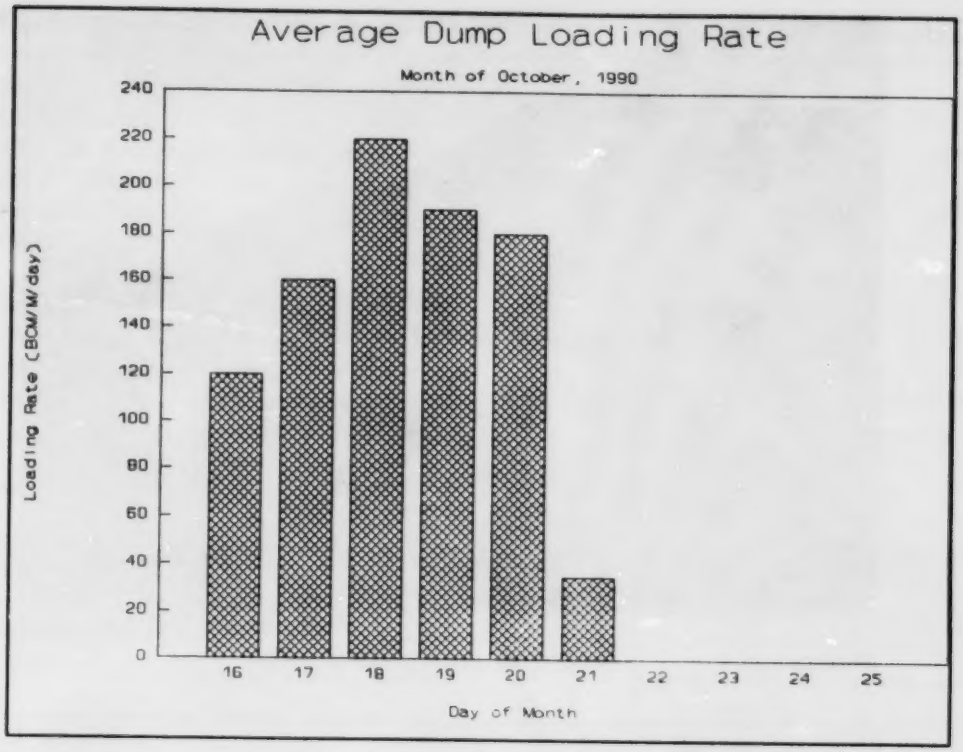
- Strain softening foundation soils, given the large strains and deformations observed a reduction in shear strength could cause instability.

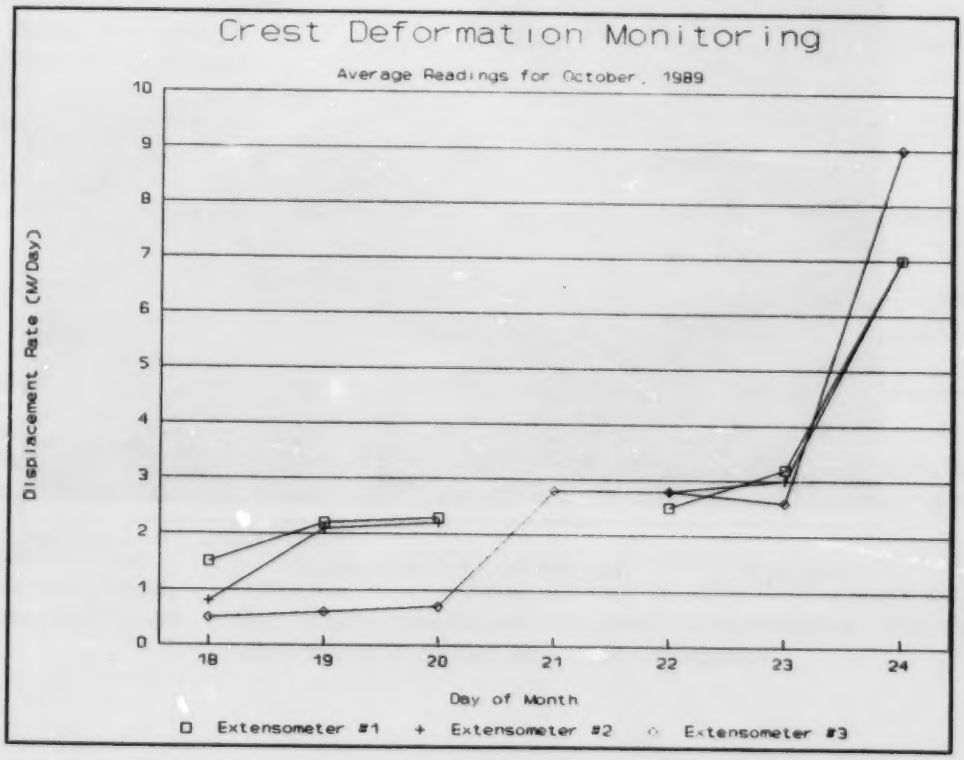
- Toe advance over frozen soils during winter months, loading rates during this period are high and would have insulated the foundation, elevated pore water pressures could be generated below this impermeable boundary reducing shear strength.

- Rounding of dump material along potential failure planes due to large strains and loads, causing a reduction in material strength.

While these factors may have all influenced stability the actual mechanics of the failure are not understood and several theories have been proposed. Visual observations before the failure provide the most useful clues. In this case large crest settlement was observed with obvious oversteepening effects on the face. The toe was identified as being well supported and not deforming as observed from the crest.

Redistribution of the loads (and therefore stresses) within the dump would be consistent with these observations, causing increased and rapid loading of the lower foundation slopes. As the strains continue, the development of potential failure planes is promoted within the dump and/or along the foundation contact. If the toe remains intact, as in this case, while the loads are redistributed sudden failure can occur when toe strengths are suddenly overcome. This mechanism for failure may have been assisted by the rapid transfer of dump load onto frozen foundation conditions with limited capacity for pore pressure dissipation.


Average Dump Loading Rate
Month of October, 1990
Loading Rate (BCM/M/day)
240
220
200
180
160
140
120
100
80
60
40
20
0
16
17
18
19
20
21
22
23
24
25
Day of Month


Crest Deformation Monitoring
Average Readings for October, 1989
Displacement Rate (M/Day)
10
9
8
7
6
5
4
3
2
1
0
18
19
20
21
22
23
24
Day of Month
Extensometer #1
Extensometer #2
Extensometer #3

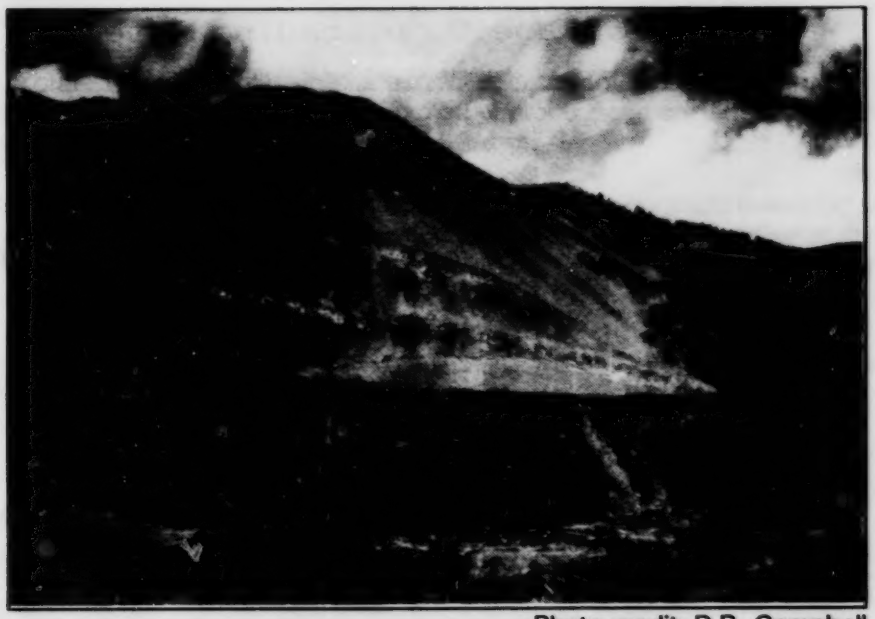


Photo credit: D.B. Campbell

Photograph 1: Record 15, prior to dump failure.

Photo credit: D.B. Campbell

Photograph 2: Record 15 After failure event

MINE DUMP FAILURE SUMMARY — RECORD NO. 16

MINE: D - Open pit coal
DUMP NAME: A - Active at time of failure.
DATE OF FAILURE: November 11, 1985
DUMP HEIGHT: 150 m (crest at 2140 m, toe at elevation 1990 m)
FAILURE VOLUME: 200,000 m^3
RUNOUT DIST.: 500 m

GENERAL DATA:

Topography Average slope 28°; concave downward in profile.
Geometry Unconfined sidehill fill.
Foundation Veneer of granular colluvial soils, silty sand and gravel, thickest on lower slopes, overlying folded sedimentary bedrock. Previous failure debris exists along valley floor.
Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH $\phi'(°)$, C'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	<#200
SHALE/MUDSTONE (~50)	LOW	35°	LOW		
SILTSTONE (~45)	HIGH		MODERATE		
SANDSTONE (5)	HIGH		MODERATE-GOOD		

DESIGN ASSUMPTIONS:

Material Strengths Dump $\phi'=37°$, $c'=0$; Foundation $\phi'=33°$, $c'=0$
Piezometric Assumptions Drained (see legend)
Method of Stability Calculation Sarma
Design Safety Factor 1.1 (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
100-200m = 100	1-50 Mm^3 = 50	37° = 100	25-32° = 100	200	200
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
200	200	100	100	0	1350/1800

FAILURE DETAILS:

Loading rate Loading rate for period prior to failure approximately 150 BCM/m/day.
Monitoring Monitor data unreliable, due to poor monitor placement, operation, and recording.
Climate Data Climate not considered a factor of instability.
Indicated Mode Rotational through dump material, foundation not a factor in failure.
Indicated Cause Poor quality material including coal stringer material; high loading rate; additional load applied after initial deformation.

DISCUSSION

The dump consisted of very poor quality material including highly fractured fine grained siltstone and mudstone of low durability, and a substantial amount (up to 20% by volume) of coal spoil originating from uneconomic coal stringers. The foundation and geometry were such that little support was offered at the toe of the dump, however the rotational failure was more likely caused by the other factors presented, rather than instability at the toe.

The failure was characterized by a rotational slump, indicative of relatively homogeneous fine grained soils. The material probably had a relatively high moisture content adding to its unit weight. The dump experienced fairly high average loading rates and probably had higher peak rates prior to the failure. As with previous dump failures at this location, subsequent loading of a lift placed on the platform to maintain grade after the initial "settlement" probably increased the extent of the instability. Further additional lifts were placed to overcome "settlement" up to the time of failure. Increasing the load on a potential failure plane is a certain method for promoting further and perhaps more widespread instability.

MINE DUMP FAILURE SUMMARY — RECORD NO. 17

MINE: D - Open pit coal
DUMP NAME: B - Active at time of failure.
DATE OF FAILURE: May 31, 1985
DUMP HEIGHT: 140 m
FAILURE VOLUME: 2.5×10^6 m^3
RUNOUT DIST.: 600 m

GENERAL DATA:

Topography Average slope 28°; concave downward in profile.
Geometry Unconfined sidehill fill, fan shaped in plan.
Foundation Veneer of granular colluvial soils, silty sand and gravel, thickest on lower slopes, overlying folded sedimentary bedrock.
Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH $\phi'(°)$, C'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	<#200
SHALE/MUDSTONE (~50)	LOW	35°	LOW		
SILTSTONE (~45)	HIGH		MODERATE		
SANDSTONE (5)	HIGH		MODERATE-GOOD		

DESIGN ASSUMPTIONS:

Material Strengths Dump $\phi'=37°$, $c'=0$; Foundation $\phi'=33°$, $c'=0$
Piezometric Assumptions Drained (see legend)
Method of Stability Calculation Sarma
Design Safety Factor 1.1 (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
100-200 m = 100	1-50 Mm^3 = 50	37° = 100	25-32° = 100	100	200
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
200	200	100	200	0	1350/1800

FAILURE DETAILS:

Loading rate Loading rate not reported, may have been a factor of instability.
Monitoring Monitoring data not reported.
Climate Data Precipitation not considered a factor, groundwater recharge by meltwater a factor.
Indicated Mode Toe failure due to yielding foundation causing loss of support and non-circular rotation within dump material.
Indicated Cause Fine material leading to oversteepening; promontory developed with little support; saturated, weak foundation soils; foundation seepage pressure; additional load applied after initial deformation.

DISCUSSION

The dump was characterized by:

- poor material quality;
- wet foundation conditions including seepage points; and,
- weak foundation material as indicated by observed material creep and tilting trees.

The dump material consisted of a high proportion of carbonaceous mudstone of very low durability, and may have had a loading rate sufficient to cause oversteepening of the fine grained material. In addition, the construction of the dump had allowed the formation of a promontory, the slopes and toe of which have poor confinement and therefore minimum support.

Initial settlement on May 30 may have been caused by recharge of groundwater as a result of spring melt causing increased foundation seepage pressure at the toe, and/or saturation of toe material causing a reduction in shear strength. The subsequent loading of a lift placed on the platform to maintain grade probably increased the extent of the instability. Further lifts were placed to overcome "settlement" up to the time of failure. Increasing the load on a potential failure plane is a certain method for promoting further and perhaps more widespread instability.

MINE DUMP FAILURE SUMMARY — RECORD NO. 18

MINE: D - Open pit coal
DUMP NAME: B - Active at time of failure.
DATE OF FAILURE: March 20, 1983
DUMP HEIGHT: 160 m
FAILURE VOLUME: 400,000 m^3
RUNOUT DIST.: 700 m

GENERAL DATA:

Topography Average slope 28°; concave downward in profile.
Geometry Unconfined sidehill fill, fan shaped in plan.
Foundation Veneer of granular colluvial soils, silty sand and gravel, thickest on lower slopes, overlying folded sedimentary bedrock.
Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH $\phi'(°)$, c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	<#200
SHALE/MUDSTONE (~50)	LOW	35°	LOW		
SILTSTONE (~45)	HIGH		MODERATE		
SANDSTONE (5)	HIGH		MODERATE-GOOD		

DESIGN ASSUMPTIONS:

Material Strengths Dump $\phi'=35°$, $c'=0$; Foundation $\phi'=32°$, $c'=0$
Piezometric Assumptions Drained (see legend)
Method of Stability Calculation Sarma
Design Safety Factor 1.1 (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
100-200 m = 100	1-50 Mm^3 = 50	37° = 100	25-32° = 100	200	200
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
200	200	200	100	0	1450/1800

FAILURE DETAILS:

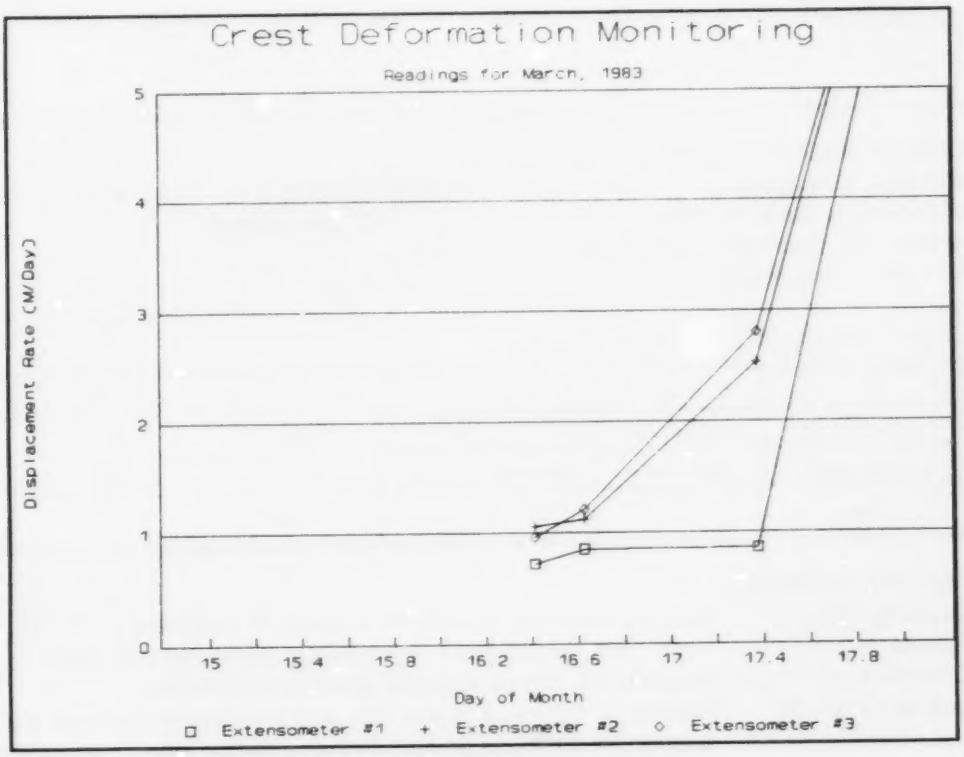
Loading rate Loading rate not considered a factor of instability.
Monitoring Peak crest deformation of 5.5 m/day hours before failure.
Climate Data Precipitation not considered a factor of instability.
Indicated Mode Rotational failure of dump toe and foundation material causing loss of support for the mass above and basal sliding along the foundation contact.
Indicated Cause High fines content causing oversteepening; snow and saturated soils at foundation contact; foundation seepage; limited toe support.

DISCUSSION

There were a number of factors contributing to dump instability:

- the dump consisted of very poor quality material including wet fine grained material and carbonaceous mudstone of low durability;
- the foundation and geometry were such that little support was offered at the toe of the dump;
- in addition, the foundation was observed to have seepage discharge in the vicinity of the failed dump, and an accumulation of snow was captured on the foundation contact during construction.

The failure was characterized by a rotational slump of the toe material caused by saturation of fine grained material by foundation seepage springs. The toe of the dump was free to move due to little confinement. Once this occurred the mass of dump material above became mobilized along the weak basal plane defined by the foundation contact, with contained snow and seepage pressure. The failure was reported to be a Sturzstrom type failure defined by a rapid high energy release causing great velocity due to lower dynamic shear strengths. The mass may have been rapidly accelerated to this type of failure due to the very low shear strength offered by the foundation contact once toe support was removed.



MINE DUMP FAILURE SUMMARY — RECORD NO. 19

MINE: D - Open pit coal.
DUMP NAME: B - Active at time of failure.
DATE OF FAILURE: May 11, 1983
DUMP HEIGHT: 168 m
FAILURE VOLUME: 720,000 m^3
RUNOUT DIST.: 320 m

GENERAL DATA:

Topography Toe slope = 16°; average = 17°; linear shape in profile.
Geometry Unconfined sidehill fill, no 3D wedging effect, linear in plan.
Foundation Mantle of colluvial silty sand and angular gravel on folded sedimentary bedrock.
Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH $\phi'(°)$, $c'(kPa)$	DURABILITY (%)	PARTICLE SIZE (%) >300mm	<#200
SANDSTONE	(N/A)	35°,0	MOD. - GOOD		
SILTSTONE	(N/A)		SD = 96 %		
SHALE/MUDSTONE	(N/A)		SD = 85 %		

DESIGN ASSUMPTIONS:

Material Strengths Dump $\phi'=35°$, $c'=0$; Foundation $\phi'=32°$, $c'=0$
Piezometric Assumptions Drained (see legend)
Method of Stability Calculation Sarma
Design Safety Factor ~1.2 (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
100-200 m = 100	1-50 Mm^3 = 50	37° = 100	10-25° = 50	100	200
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
200	200	200	100	50	1350/1800

FAILURE DETAILS:

Loading rate Loading rate not considered a factor of instability.
Monitoring Visual observations include a slow and gradual deformation forming 5-6 steps each 0.25 to 0.5 m vertical.
Climate Data Precipitation not reported, spring melt causing groundwater recharge and foundation seepage pressure.
Indicated Mode Yielding toe / basal along foundation contact.
Indicated Cause High foundation pore pressure; high dump pore pressure; redistribution stresses.

DISCUSSION

The dump consists of a large percentage of fines and readily degradable carbonaceous mudstone. Foundation conditions are comparatively good with relatively shallow slopes of bedrock and free draining colluvial soils. Foundation seepage pressures and infiltration are suspected however, especially during periods of groundwater recharge.

The failure was characterized by slow and gradual deformation over a period of several days. The crest deformed in a series of steps progressively until a total of 6 individual features formed, each with a vertical displacement of 0.5 m. On the day of the failure, visual observations were recorded of a prominent face bulge coincident with increased surface cracking on the platform. These deformations signify large redistribution of stresses within the dump, as the face bulge rapidly increased in size just prior to failure. The increased load on the foundation due to these sudden changes in stresses can be sufficient to cause pore pressure generation within the foundation in excess of dissipation and thus significantly reduce the shear strength of the foundation materials causing failure along the foundation contact.

MINE DUMP FAILURE SUMMARY — RECORD NO. 20

MINE: D - Open pit coal
DUMP NAME: C - Active at time of failure.
DATE OF FAILURE: November 22, 1989
DUMP HEIGHT: 250 m
FAILURE VOLUME: 2.0×10^6 m^3
RUNOUT DIST.: 1750 m (average 4.5° runoff slope for lower 1600 m)

GENERAL DATA:

Topography Toe slope = 22°; mid slope = 30°; crest slope = 40°; concave downward in profile.

Geometry Unconfined sidehill wrap around for upper dumps. No 3D wedging effect.

Foundation Sandy gravel colluvium and slopewash (0-2 m) thick on steeper bedrock slopes, glacial till and/or fluvial sediments on lower slopes. Failure debris and saturated soft disturbed soils at toe.

Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH $\phi'(^\circ)$, c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	PARTICLE SIZE (%) <#200
SILTSTONE (70)	MED	37°, 0	MOD-HIGH	N/A	N/A
SHALE (20)	LOW		LOW		
SANDSTONE (10)	HIGH		HIGH		

DESIGN ASSUMPTIONS:

Material Strengths Dump ϕ'=37°, c'=0; Foundation ϕ'=33°, c'=0

Piezometric Assumptions Drained (see legend)

Method of Stability Calculation Janbu

Design Safety Factor 1.4 ultimate (static), ~1.0 intermediate (static).

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
>200 m = 200	1-50 Mm^3 = 50	37° = 100	25-32° = 100	200	200
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
100	200	100	200	0	**1450**/1800

FAILURE DETAILS:

Loading rate Average 290 BCM/m/day - 2 weeks prior to event, then infrequently.

Monitoring Average crest deformation rate of 2 m/day while dumping continued, and peaks of 5 m/day prior to failure.

Climate Data Precipitation not considered a factor of instability.

Indicated Mode Lateral yielding of foundation toe soils at the contact causing loss of support for the mass above and rotational slump through dump material.

Indicated Cause Liquefaction of soft saturated organics and debris at toe; high loading and strain rate; poor material quality.

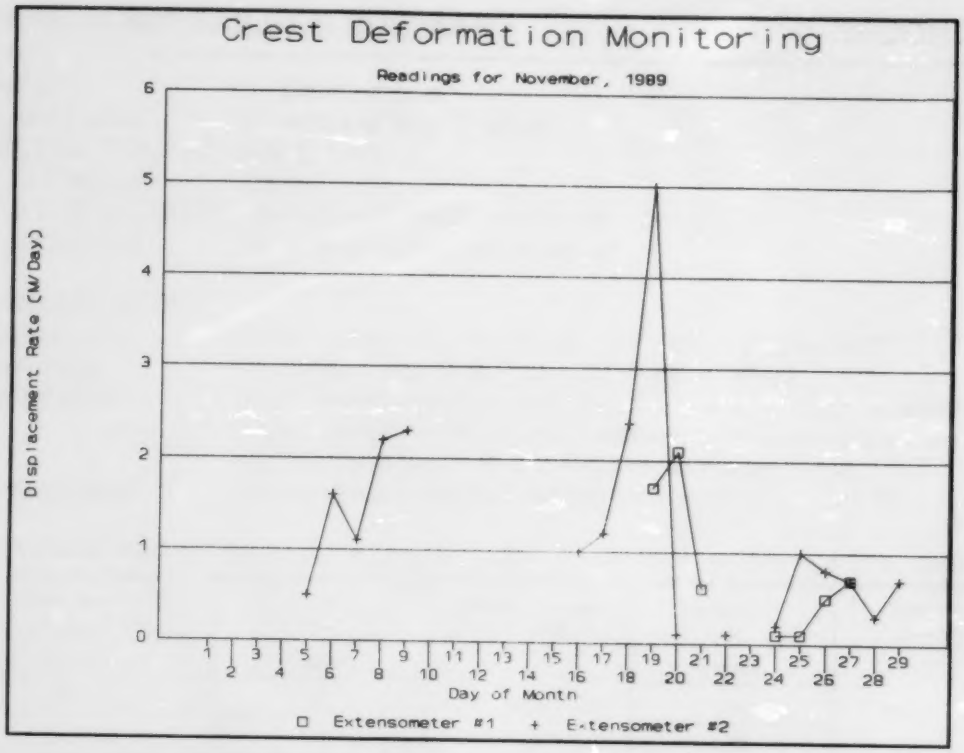
DISCUSSION

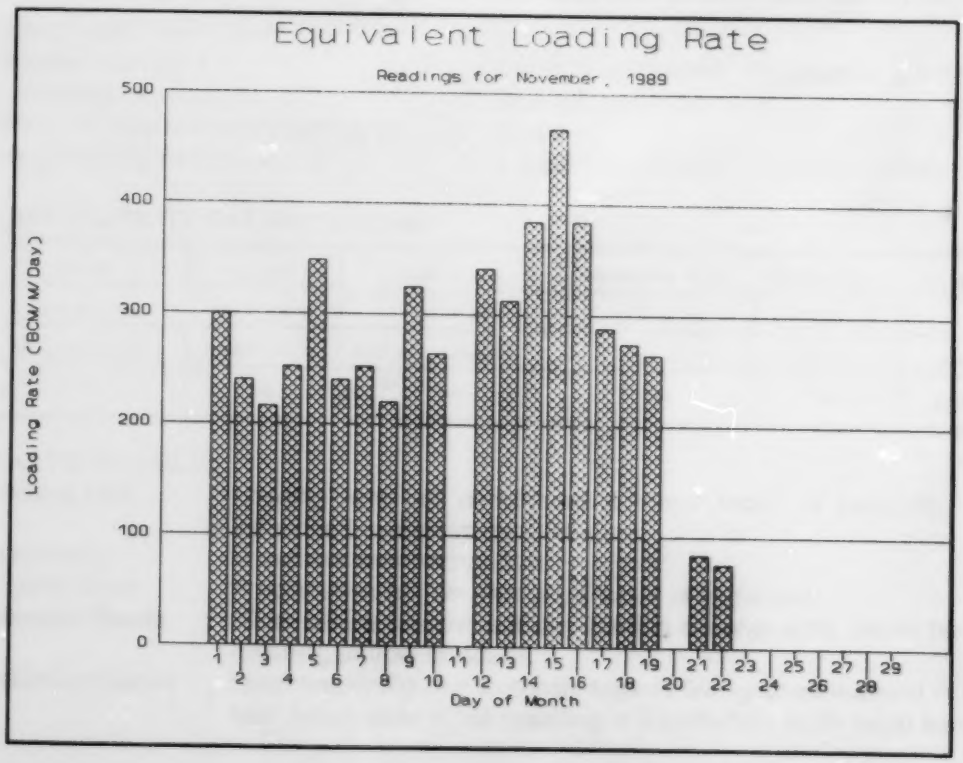
The dump consists of:

- poor-medium material quality;
- steep foundation slopes;
- poor toe confinement at the time of the failure; and,
- the presence of soft weak organic soils and 5-10 m thickness of debris from previous failure (mudflow) events; and,
- the toe soils were saturated by their proximity to a nearby tributary to a creek.

The failure was characterized by a 350 m long backscarp up to 45 m from the original crest, and resembled a low viscosity flow over relatively flat ground, indicative of the high moisture content of the soils at the toe region. The failure debris attained a velocity of 70 km/h estimated by the height of the flow at a change in direction.

The cause of the failure appears to be due to the presence of saturated soils and debris at the advancing toe. Rapid loading of these soils did not permit the pore pressure dissipation required to maintain stability. Once the failure was initiated it quickly spread as loading of weak soils by the debris perpetuated the mechanism of failure, creating a flowing type phenomenon. Loading rates of up to 450 BCM/m/day were recorded for areas of the dump, however these were not necessarily placed in the area of the failure. The reported loading rate of 290 BCM/m/day represents a large placement obviously in excess of the ability of the foundation materials to dissipate pore pressure.


Crest Deformation Monitoring
Readings for November, 1989
Displacement Rate (M/Day)
0
1
2
3
4
5
6
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
Day of Month
□ Extensometer #1 + Extensometer #2


Equivalent Loading Rate
Readings for November, 1989
Loading Rate (BCM/M/Day)
0
100
200
300
400
500
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29
Day of Month

MINE DUMP FAILURE SUMMARY — RECORD NO. 21

MINE: D - Open pit coal
DUMP NAME: C - Active at time of failure.
DATE OF FAILURE: July 1, 1985
DUMP HEIGHT: 275 m
FAILURE VOLUME: Not reported, estimated 200,000 - 300,000 m^3
RUNOUT DIST.: 500 m (average 6° runout slope)

GENERAL DATA:

Topography Steep valley sides; toe slope = 21°; upper slopes to 35°.
Geometry Unconfined sidehill fill, some 3D wedging effect.
Foundation Sandy gravel colluvium and slopewash (0-2 m) thick on steeper bedrock slopes, glacial till and/or fluvial sediments on lower slopes. Failure debris and saturated soft and disturbed organic soils at toe.
Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH $\phi'(°)$, c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	<#200
SILTSTONE (70)	MED	37°, 0	MOD-HIGH	N/A	N/A
SHALE (20)	LOW		LOW		
SANDSTONE (10)	HIGH		HIGH		

DESIGN ASSUMPTIONS:

Material Strengths Dump ϕ'=37°, c'=0; Foundation ϕ'=32°-35°, c'=0,
Piezometric Assumptions Drained (see legend)
Method of Stability Calculation Janbu
Design Safety Factor 1.4 ultimate (static), ~1.0 intermediate (static).

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
>200 m = 300	1-50 Mm^3 = 50	37° = 100	25-32° = 100	100	300
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
100	200	100	100	50	1300/1800

FAILURE DETAILS:

Loading rate Loading rate not considered a major factor of instability, may have influenced oversteepening of crest.
Monitoring Unreliable monitoring data.
Climate Data Precipitation not considered a factor of instability.
Indicated Mode Sliver failure causing sudden loading of weak soils below the dump toe resulting in flow of debris.
Indicated Cause Oversteepening due to percentage of fine grained material in dump; soft foundation soils at toe resulting in liquefaction upon rapid loading.

DISCUSSION

The dump contained a sufficient amount of wet fine grained material to cause oversteepening of the crest. The loading rate, although not reported, probably also contributed to the oversteepening. The natural soils at and below the toe of the dump consisted of previously disturbed saturated organic soils. When the sliver failure of the dump material rapidly loaded these soils liquefaction occurs causing the debris to flow a substantial distance.

The debris and disturbed organic soils remained in a near saturated consistency at the valley bottom for some time. Later sliver failures and runout from this dump were influenced by the presence of this material.

MINE DUMP FAILURE SUMMARY — RECORD NO. 22

MINE: D - Open pit coal
DUMP NAME: C - Active at time of failure.
DATE OF FAILURE: July 12, 1986
DUMP HEIGHT: 275 m (crest at elev. 2100 m, toe at elev. 1825 m)
FAILURE VOLUME: 240,000 m^3
RUNOUT DIST.: 400 m

GENERAL DATA:

Topography Steep valley sides; toe slope = 21°; upper slopes to 35°; concave downward in profile.

Geometry Unconfined sidehill fill, some 3D wedging effect.

Foundation Sandy gravel colluvium and slopewash (0-2 m) thick on steeper bedrock slopes, glacial till and/or fluvial sediments on lower slopes. Failure debris and saturated soft disturbed soils at toe.

Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH $\phi'(^\circ)$, c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	PARTICLE SIZE (%) <#200
SILTSTONE (70)	MED	37°, 0	MOD-HIGH	N/A	N/A
SHALE (20)	LOW		LOW		
SANDSTONE (10)	HIGH		HIGH		

DESIGN ASSUMPTIONS:

Material Strengths Dump ϕ'=37°, c'=0; Foundation ϕ'=32°-35°, c'=0,

Piezometric Assumptions Drained (see legend)

Method of Stability Calculation Janbu

Design Safety Factor 1.4 ultimate (static), ~1.0 intermediate (static).

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
>200 m = 200	1-50 Mm^3 = 50	37° = 100	25-32° = 100	100	200
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
200	200	200	100	0	**1450/1800**

FAILURE DETAILS:

Loading rate Loading rate not considered a major factor of instability, may have influenced oversteepening of crest.

Monitoring Unreliable monitoring data.

Climate Data Total of 32 mm rain for month, spring meltwater contributing to groundwater recharge and foundation seepage pressure.

Indicated Mode Sliver failure causing sudden loading of weak soils below the dump toe resulting in flow of debris.

Indicated Cause Oversteepening due to percentage of fine grained material in dump; soft foundation soils at toe resulting in liquefaction upon rapid loading.

DISCUSSION

The dump contained a sufficient amount of wet fine grained material to cause oversteepening of the crest. The material was influenced by precipitation and infiltration causing an increase in unit weight and apparent cohesion. The loading rate, although not reported, probably also contributed to the oversteepening. The natural soils at and below the toe of the dump consisted of previously disturbed saturated organic soils and debris from previous failures. When the sliver failure of the dump material rapidly loaded these soils liquefaction occurred causing the debris to flow substantial distance. Spring melt water had previously caused brought the soils to saturation, and probably promoted flow by increasing foundation seepage pressure.

The debris and disturbed organic soils remained in a near saturated consistency at the valley bottom for some time. Later sliver failures and runout from this dump were influenced by the presence of this material.

MINE DUMP FAILURE SUMMARY — RECORD NO. 23

MINE: E - Open pit coal
DUMP NAME: A - Active at time of failure.
DATE OF FAILURE: March 24, 1990
DUMP HEIGHT: 170 m (Crest at elev. 2170 m, toe at elev 2000 m)
FAILURE VOLUME: Volume of slide debris not reported, estimated to be 200,000 m^3
RUNOUT DIST.: 500 m

GENERAL DATA:

Topography Toe slope=28°; mid slope=33°; crest slope=39°; slope below toe region in excess of 37°; concave downward in profile; convex below toe in profile.

Geometry Unconfined sidehill fill, convex crest at time of failure.

Foundation Veneer of silty sand and gravel colluvium, thicker on lower slopes overlying interbedded carbonaceous shale, clayey siltstone, and fine to medium grained sandstone bedrock.

Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH ϕ'(°), c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	<#200
SANDSTONE (30-60)	150	37°, 0	SD=93-98%	60	0
SHALE (25-50)	25-50			40	5
SILTSTONE (40-60)	100			25	10

DESIGN ASSUMPTIONS:

Material Strengths Dump ϕ'= 37°, c'=0, Foundation ϕ'= 32°, c'=0
Piezometric Assumptions Drained
Method of Stability Calculation Janbu, Morgenstern-Price
Design Safety Factor 1.1 (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
100-200m = 100	1-50Mm^3 = 50	37° = 100	>32° = 200	200	200
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
200	200	100	200	0	1550/1800

FAILURE DETAILS:

Loading rate Loading rate estimated to be approximately 250 BCM/m/day.

Monitoring Deformations up to 1.2 m /day prior to failure.

Climate Data Precipitation not considered a factor of instability, very cold temperatures.

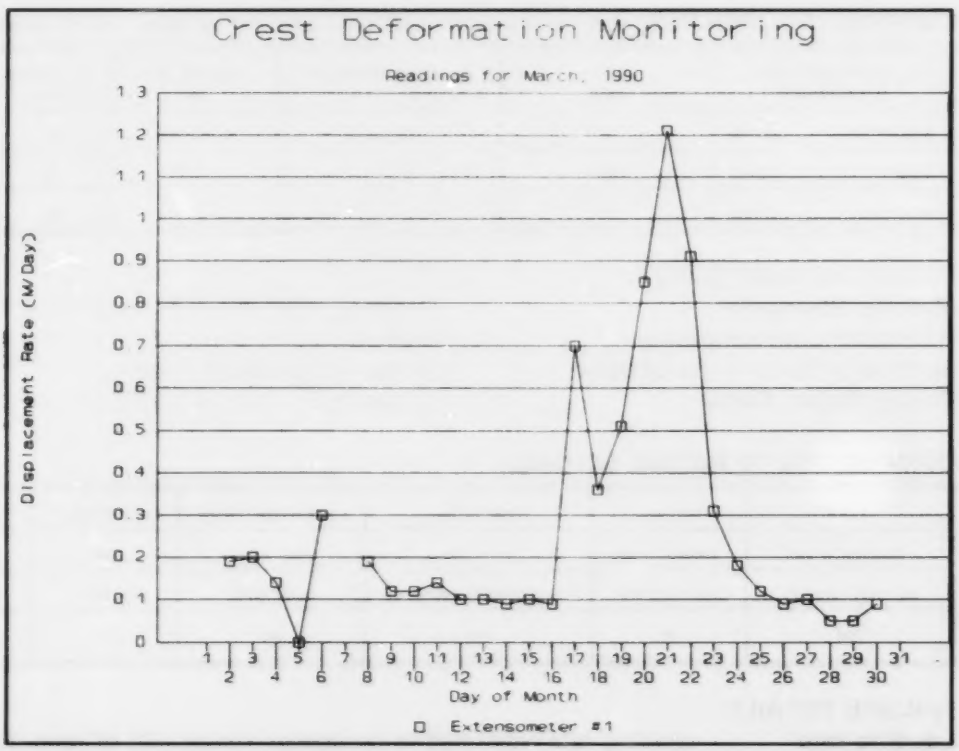
Indicated Mode Toe failure of adjacent dump, progressive non-circular rotational slump within new dump construction, saturated flow failure

Indicated Cause High pore pressure in toe of adjacent dump, overloaded suddenly by new dump construction; steep slopes; fine material; high loading rates

DISCUSSION

Dump construction was adjacent to an established dump, and was advanced such that the stability was theoretically improved in the artificial V shape defined by the existing topography and the original dump. The original dump was constructed with intermittent dumping of poor quality fine grained material. This material was observed throughout the slope and, more importantly, at the toe. The original dump was exhibiting signs of deformation such as bulging at the toe, considered to be caused by foundation seepage pressures. The seepage pressure zone is thought to be related to the location of a well defined creek gully on the natural slope.

As the new dump was constructed high loading rates caused rapid toe advance and loaded the bulge and toe of the adjacent dump. This rapid loading caused increased pore pressure generation in excess of the dissipation rate causing toe failure. Upon loss of support from the toe the unsupported mass above failed, including substantial quantity of poor quality fine grained material. Slopes below the toe were much steeper and limited confinement was available. The material appeared to flow in a fluid like form and was observed to be saturated, presumably due to foundation seepage in the original gully.



MINE DUMP FAILURE SUMMARY — RECORD NO. 24

MINE: E - Open pit coal
DUMP NAME: A - Active at time of failure.
DATE OF FAILURE: May 2, 1990
DUMP HEIGHT: 170 m (crest at elev. 2170 m, toe at elev. 2000 m)
FAILURE VOLUME: Volume of slide debris estimated to be 200,000 m^3
RUNOUT DIST.: 750 m

GENERAL DATA:

Topography Toe slope=28°; mid slope=33°; crest slope=39°; slope below toe region in excess of 37°; concave downward in profile; convex below toe in profile.

Geometry Unconfined sidehill fill, convex crest at time of failure

Foundation Veneer of silty sand and gravel colluvium, thicker on lower slopes overlying interbedded carbonaceous shale, clayey siltstone, and fine to medium grained sandstone bedrock. Failure debris from previous events at toe of slope.

Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests

DUMP ROCK TYPE (% BY VOLUME)		UCS (MPa)	ESTIMATED STRENGTH $\phi'(^\circ)$, C'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	<#200
SANDSTONE	(30-60)	150	37°, 0	SD=93-98%	60	0
SHALE	(25-50)	25-50			40	5
SILTSTONE	(40-60)	100			25	10

DESIGN ASSUMPTIONS:

Material Strengths Dump ϕ'= 37°, c'=0, Foundation ϕ'= 32°, c'=0

Piezometric Assumptions Drained

Method of Stability Calculation Janbu, Morgenstern-Price

Design Safety Factor 1.1 (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
1-200m = 100	1-50Mm³ = 50	37° = 100	>32° = 200	200	200
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
200	200	100	200	0	1550/1800

FAILURE DETAILS:

Loading rate Loading rate estimated to be approximately 250 BCM/m/day.

Monitoring Deformations up to 1.2 m /day.

Climate Data 3 mm rain on day of failure, no significant precipitation previously.

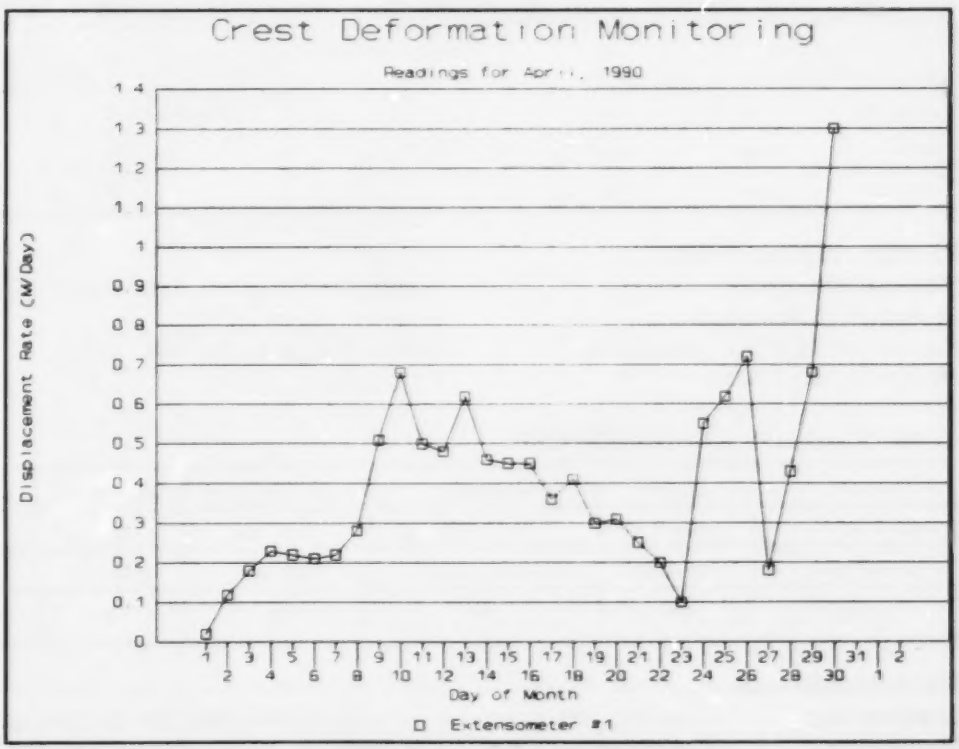
Indicated Mode Toe failure of adjacent dump, progressive non-circular rotational slump within new dump construction, saturated flow failure

Indicated Cause High pore pressure in toe of adjacent dump, overloaded suddenly by new dump construction; steep slopes; fine material; high loading rates.

DISCUSSION

Dump construction was adjacent to an established dump, and was advanced in a manner such that stability was theoretically improved in the artificial V shape defined by the existing topography and the original dump. The original dump was constructed with intermittent dumping of poor quality fine grained material. This material was observed throughout the slope and, more importantly, at the toe. The original dump had experienced previous failure under similar conditions, including deformation such as bulging at the toe, considered to be caused by increased foundation seepage pressures. The seepage pressure zone was thought to be related to the location of a well defined creek gully on the natural slope.

As the new dump was constructed high loading rates caused rapid toe advance, and loaded the bulge and toe of the adjacent dump. This rapid loading caused increased pore pressure generation in excess of the dissipation rate causing toe failure. Upon loss of support from the toe the unsupported mass above failed, including substantial quantity of poor quality fine grained material. Slopes below the toe are much steeper and limited confinement was available. The material appeared to flow in a fluid like form and was observed to be saturated, presumably due to foundation seepage via the original gully. Runout of failure debris was increased by the presence of saturated soils on the valley floor from previous failure.



MINE DUMP FAILURE SUMMARY — RECORD NO. 25

MINE: E - Open pit coal
DUMP NAME: B - Active at time of failure.
DATE OF FAILURE: January 29, 1991
DUMP HEIGHT: 195 m (crest at elev. 1675 m, toe at elev. 1480 m)
FAILURE VOLUME: 400,000 m^3
RUNOUT DIST.:

GENERAL DATA:

Topography Toe slope=40°; mid slope=30°; crest slope=30°; linear-convex shape in profile

Geometry Unconfined sidehill fill; convex shape at time of failure.

Foundation Veneer colluvial silty sand and gravel on slopes, blanket (4-8 m) of sand and gravel overlying 10-17 m dense till on lower slopes, overlying bedrock across toe area in creek bottom. Bedrock slopes of interbedded carbonaceous shale, clayey siltstone, and medium grained sandstone.

Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH $\phi'(°)$, $c'(kPa)$	DURABILITY (%)	PARTICLE SIZE (%) >300mm	PARTICLE SIZE (%) <#200
SANDSTONE (30-60)	150	37°, 0	SD=93-98%	60	0
SHALE (25-50)	25-50			40	5
SILTSTONE (40-60)	100			25	10

DESIGN ASSUMPTIONS:

Material Strengths Dump $\phi'=37°, c'=0$; Foundation $\phi'=37°, c'=0$

Piezometric Assumptions i) Drained, and; ii) Pore pressure response in foundation material

Method of Stability Calculation Janbu, Morgenstern-Price

Design Safety Factor 1.15, 1.6

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
1-200m = 100	1-50Mm³ = 50	37° = 100	25-32° = 100	100	100
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
200	200	100	200	0	1250/1800

FAILURE DETAILS:

Loading rate Average loading rate for month between 100-175 m^3/m/day. Days prior to failure loading rate in excess of 200 m^3/m/day.

Monitoring Monitoring records indicate crest deformations less than 500 mm/d for period up to the day of failure.

Climate Data Precipitation not considered a factor of instability.

Indicated Mode Initially rotational slump, progressing to a larger plane failure within dump material.

Indicated Cause High loading rate; winter construction.

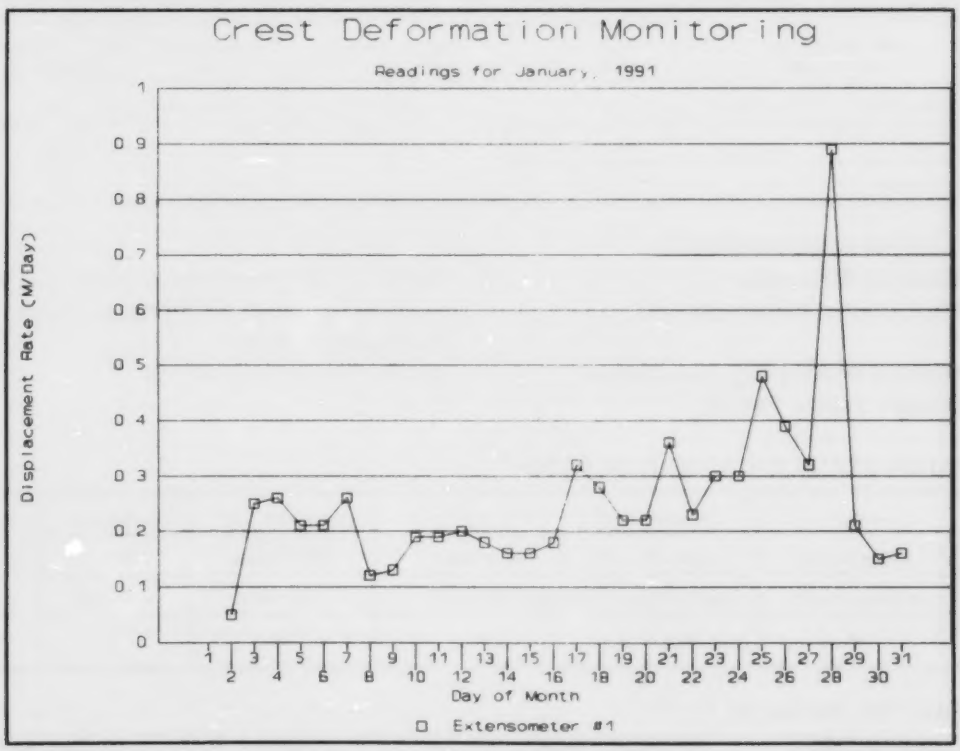
DISCUSSION

The failure was observed to be a two staged event starting initially with a drop of platform elevation forming a scarp 20 m from the crest, coincident with the failure arc appearing about halfway down the slope. After this another scarp, which represented the ultimate failure plane, was observed about 30 m from the crest, and was observed to exit the dump slope about 2/3 of the way down the slope. The failure plane was observed to be nearly parallel to the original dump slope.

The failure is attributed to high loading rates possibly causing a reduction in shear strength of the dump material along distinct planes, however other factors were also certainly of influence, including:

- winter construction and trapped snow forming a continuous plane of weakness parallel to the dump face;
- placement of fine grained poor quality material forming a plane of weakness, or altering the piezometric conditions within the dump.

The foundation remained intact during the failure and cannot be considered a factor of instability.



MINE DUMP FAILURE SUMMARY — RECORD NO. 26

MINE: E - Open pit coal
DUMP NAME: C - Active at time of failure.
DATE OF FAILURE: August 11, 1986
DUMP HEIGHT: 220 m
FAILURE VOLUME: 600,000 m^3
RUNOUT DIST.: 200 m (estimated)

GENERAL DATA:

Topography Average slope approximately 25-30°; foundation toe slope = 15°; concave downward in profile.

Geometry Unconfined sidehill fill, no 3D wedging effect.

Foundation Veneer of colluvial silty sand and gravels less than 0.3 m above dump toe elevation, well graded outwash and lacustrine deposits below dump toe. Overlying bedrock slopes of interbedded carbonaceous shale, clayey siltstone, and fine to medium grained sandstone.

Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH $\phi'(^\circ)$, c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	<#200
SANDSTONE (30-60)	150	37°, 0	SD=93-98%	60	0
SHALE (25-50)	25-50			40	5
SILTSTONE (40-60)	100			25	10

DESIGN ASSUMPTIONS:

Material Strengths Dump ϕ'= 37°, c'=0, Foundation ϕ'= 32°, c'=0

Piezometric Assumptions Drained

Method of Stability Calculation Janbu, Morgenstern-Price

Design Safety Factor 1.1 (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
>200m = 200	1-50Mm^3 = 50	37° = 100	25-32° = 100	100	100
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
300	200	100	200	0	**1350**/1800

FAILURE DETAILS:

Loading rate Loading rate not reported, but considered to be primary cause of instability.

Monitoring Crest deformations in excess of 1.4 m/day for day prior to failure, and peak of 6 m/day 10 hours prior to failure.

Climate Data Total of 10 mm precipitation during days prior to failure.

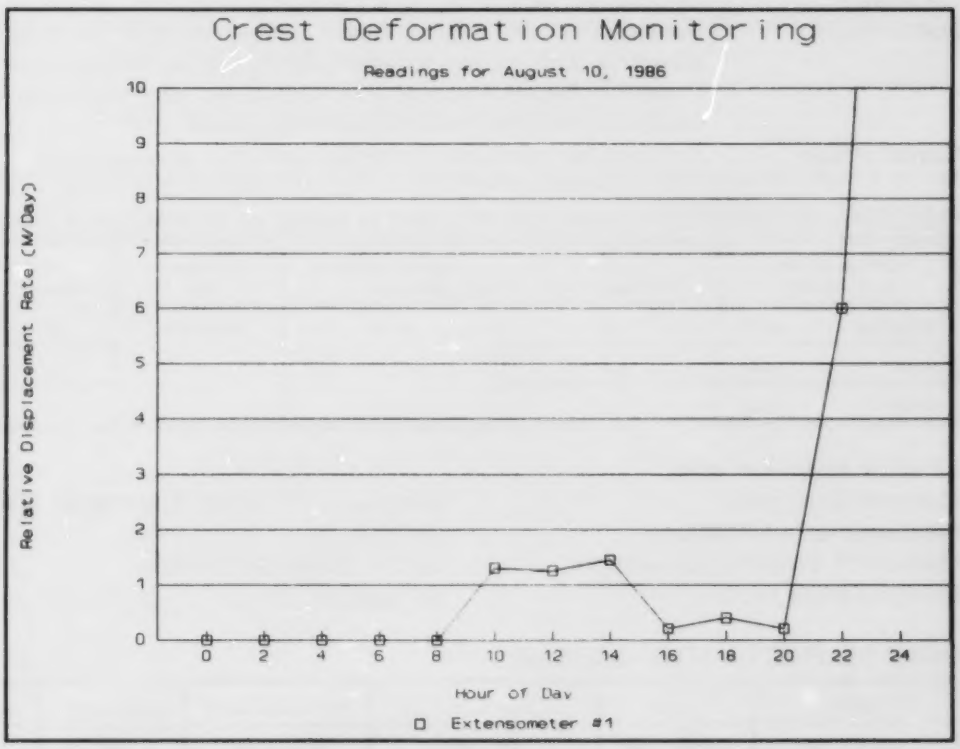
Indicated Mode Series of sliver failures within dump material.

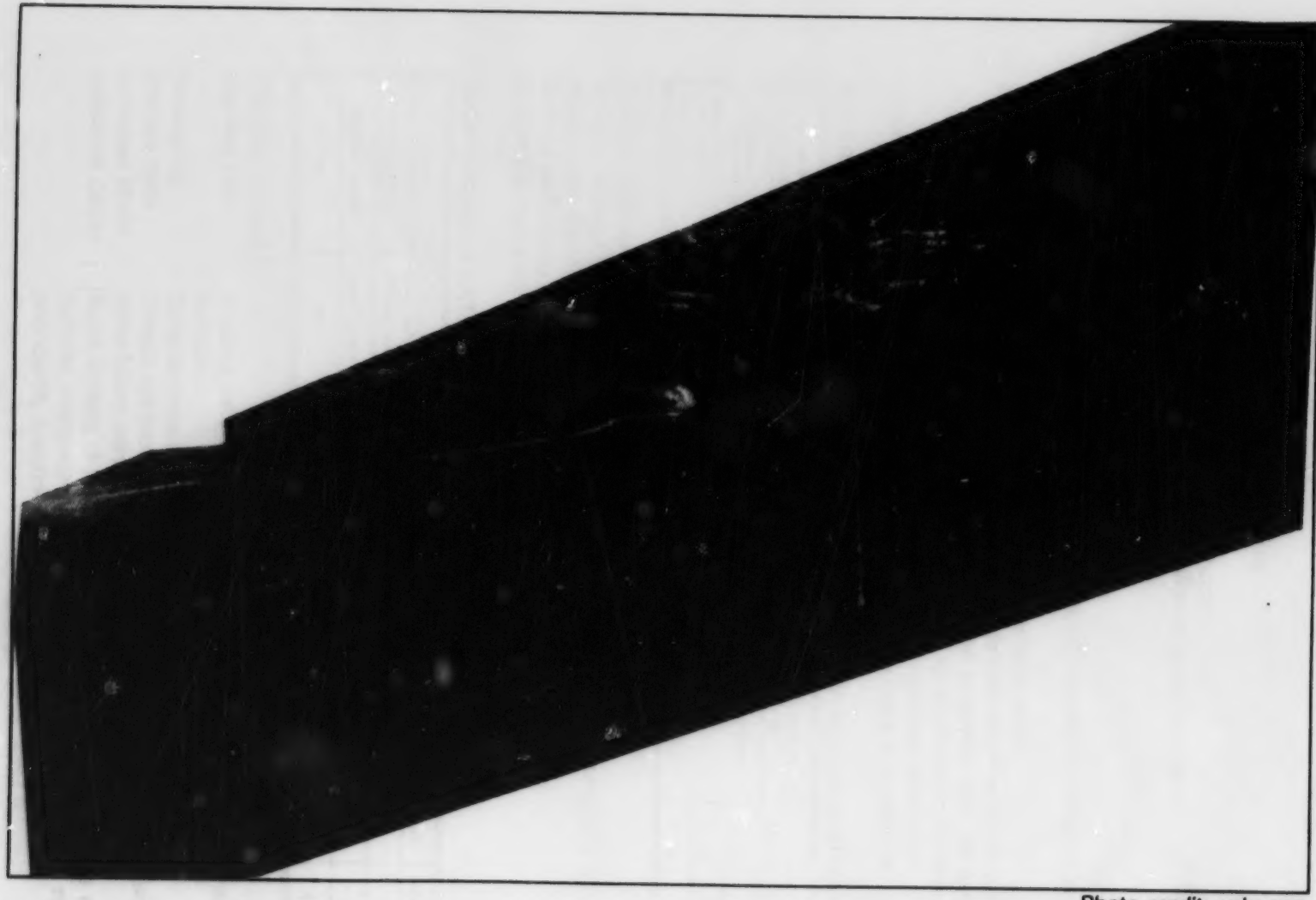
Indicated Cause High fines content and precipitation leading to oversteepening of crest due to apparent cohesion; rapid loading.

DISCUSSION

Sliver failures are generally caused by oversteepening of the crest which is related to the apparent cohesion of the fines and the rate of loading. These two factors combined in this failure to cause the series of slivers observed. Light precipitation also influenced the instability by the added moisture to fines during excavation, transportation and placement, thereby increasing the unit weight of the material.

Under these conditions of oversteepening and increased loads sliver failures are common, failing back to the material natural angle of repose. In this case the progression of one sliver to the next occurred over a period of 31 hours.





Photograph 1: Record 26 dump failure.

Photo credit: unknown

MINE DUMP FAILURE SUMMARY — RECORD NO. 27

MINE: E - Open pit coal
DUMP NAME: D - Active at time of failure.
DATE OF FAILURE: May 1, 1984
DUMP HEIGHT: Estimated 200 m (from photo)
FAILURE VOLUME: Volume of slide debris estimated to be 300,000 m^3
RUNOUT DIST.: 200 m (estimated)

GENERAL DATA:

Topography Average slope approximately 25-30°; toe slope approximately 12°; concave downward in profile.

Geometry Unconfined sidehill fill, no 3D wedging effect.

Foundation Veneer of colluvial silty sand and gravels less than 0.3 m above mid dump elevation, well graded outwash and lacustrine deposits below mid dump height. Overlying bedrock slopes of interbedded carbonaceous shale, clayey siltstone, and fine to medium grained sandstone.

Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)		UCS (MPa)	ESTIMATED STRENGTH $\phi'(^\circ)$, c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	<#200
SANDSTONE	(30-60)	150	37°, 0	SD=93-98%	60	0
SHALE	(25-50)	25-50			40	5
SILTSTONE	(40-60)	100			25	10

DESIGN ASSUMPTIONS:

Material Strengths Dump ϕ'= 37°, c'=0, Foundation ϕ'= 32°, c'=0
Piezometric Assumptions Drained
Method of Stability Calculation Janbu, Morgenstern-Price
Design Safety Factor 1.1 (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
100-200m = 100	1-50Mm³ = 80	37° = 100	25-32° = 100	100	100
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
200	200	200	200	0	1350/1800

FAILURE DETAILS:

Loading rate Loading rate not reported, but considered to be primary cause of instability.

Monitoring Crest deformations in excess of 0.5 m/day.

Climate Data Climate not reported, however meltwater is considered to significant.

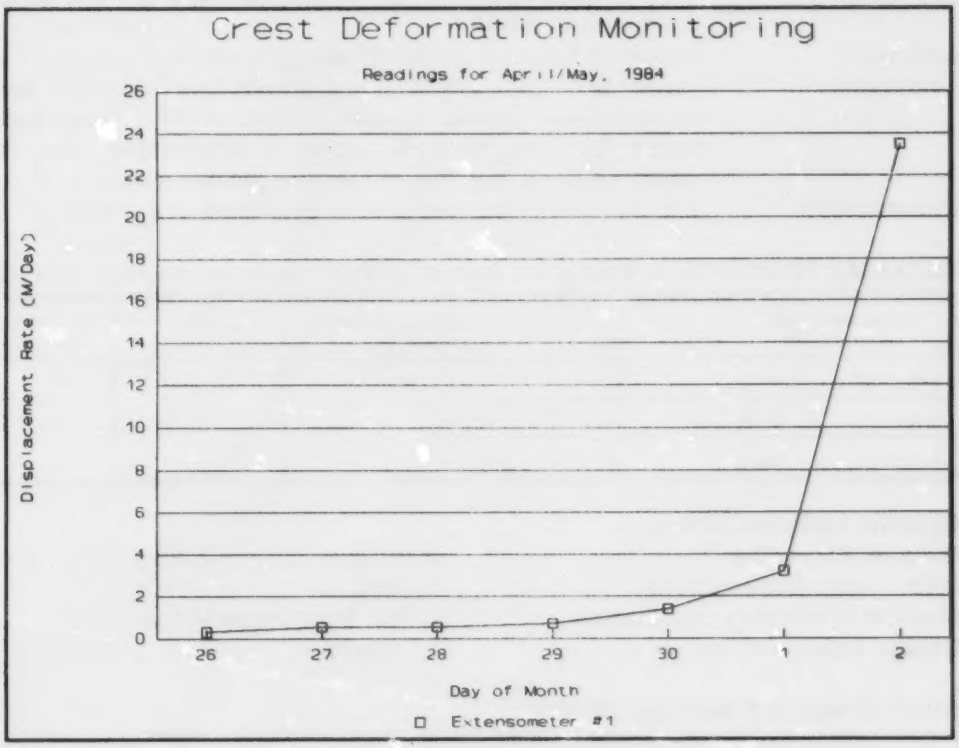
Indicated Mode Sliver failure within dump material.

Indicated Cause Rapid loading of relatively fine material including rehandle and fine coal material; oversteepening due of apparent cohesion; failed along zone of poor quality material.

DISCUSSION

This dump was characterized by poor quality material, recently saturated by spring meltwater, and placed at very high rates. Visual observations of face bulging and oversteepening at the crest were made prior to failure.

Sliver failures are generally caused by oversteepening of the crest which is related to the apparent cohesion of the fines and the rate of loading. These two factors combined in this failure to cause the sliver observed. Spring meltwater also influenced the instability due to added moisture to fines in the dump increasing the unit weight of the material.



MINE DUMP FAILURE SUMMARY — RECORD NO. 28

MINE: E - Open pit coal
DUMP NAME: E - Active at time of failure.
DATE OF FAILURE: July 1, 1982
DUMP HEIGHT: 250 m (crest at elev. 186 m, toe at elev 1610 m)
FAILURE VOLUME: 255,000 m^3, volume from dump was much smaller than subsequent mass movement of natural soils initiated by dump failure.
RUNOUT DIST.: 500 m

GENERAL DATA:

Topography Toe slope=15-20°; mid slope=23°; crest slope=35-42°; concave downward in profile.

Geometry Unconfined sidehill fill, slightly concave shape in plan, minor 3D wedging effect

Foundation Veneer of colluvial silty sand and gravels less than 0.3 m above dump toe elevation, well graded outwash and lacustrine deposits below dump toe. Overlying bedrock slopes of interbedded carbonaceous shale, clayey siltstone, and fine to medium grained sandstone.

Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)		UCS (MPa)	ESTIMATED STRENGTH ϕ'(°), c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	<#200
SANDSTONE	(30-60)	150	37°, 0	SD=93-98%	60	0
SHALE	(25-50)	25-50			40	5
SILTSTONE	(40-60)	100			25	10

DESIGN ASSUMPTIONS:

Material Strengths Dump ϕ'= 37°, c'=0; Foundation ϕ'= 32°, c'=0
Piezometric Assumptions Drained
Method of Stability Calculation Janbu, Morgenstern-Price
Design Safety Factor 1.1 (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
>200m = 200	>50Mm³ = 100	37° = 100	25-32° = 100	100	100
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
200	200	200	100	0	1400/1800

FAILURE DETAILS:

Loading rate Loading rate not considered a factor of instability.
Monitoring Monitor data not reported, visual observation just before failure indicate 0.75 m displacement in 5 minutes.
Climate Data Heavy rainfall reported for days prior to event.
Indicated Mode Rotational slump within dump material.
Indicated Cause High pore pressure in dump, due to high precipitation; steep foundation slopes in upper part of dump.

DISCUSSION

The failure was a two stage event including a relatively small rotational failure through dump material, followed by a much larger disturbance of natural soils which liquefied due to the sudden load.

There was significant rainfall during the week prior to the first event, causing deformations within the dump material. These deformations were exhibited by a dropping crest coincident with a prominent face bulge with the upper half of the dump face. Following this the toe of the dump apparently failed, leaving the upper region of the dump unsupported and causing more dump material to fail and move down slope.

The debris moved rapidly onto the soft saturated lacustrine soils in the valley bottom causing rapid increase in pore pressure and significant reduction in shear strength. The soils which were immediately disturbed moved out and repeated the mechanism over a large area, with the appearance of a mudflow.

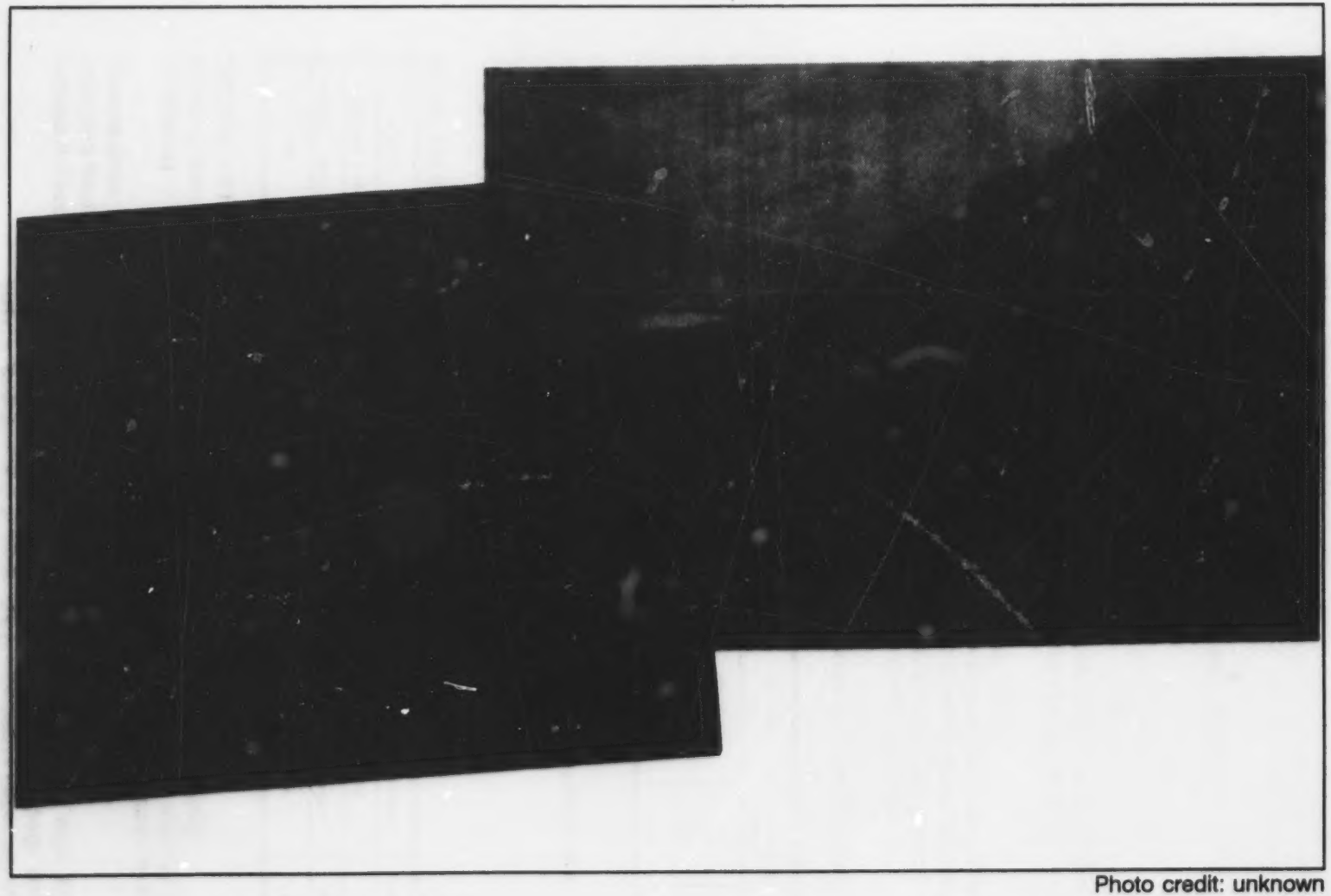


Photo credit: unknown

Photograph 1: Record 28 dump failure

MINE DUMP FAILURE SUMMARY — RECORD NO. 29

MINE: E - Open pit coal
DUMP NAME: F - Active at time of failure.
DATE OF FAILURE: August 20, 1988
DUMP HEIGHT: 150 m (crest at elev. 2182 m, toe at elev. 2030 m)
FAILURE VOLUME: 90,000 m^3
RUNOUT DIST.: 100 m

GENERAL DATA:

Topography Toe of dump was unconfined, slope below toe was approximately 40°, toe region of dump on 20° slope, remainder of slope at 32-36°, concave shape in profile, convex shape below toe.

Geometry Unconfined sidehill fill, no 3D wedging effect.

Foundation Veneer of colluvial silty sand and gravels less than 0 3 m above dump toe elevation, well graded outwash deposits below dump toe. Bedrock slopes of interbedded shale, clayey siltstone, and medium grained sandstone.

Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests. The dump had a large percentage of friable mudstone/shale.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH $\phi'(^\circ)$, c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	<#200
SANDSTONE (30-60)	150	37°, 0	SD=93-98%	60	0
SHALE (25-50)	25-50			40	5
SILTSTONE (40-60)	100			25	10

DESIGN ASSUMPTIONS:

Material Strengths Dump ϕ'= 37°, c'=0; Foundation ϕ'= 32°, c'=0
Piezometric Assumptions Drained
Method of Stability Calculation Janbu, Morgenstern-Price
Design Safety Factor 1.1 (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
100-200m = 100	1-50Mm³ = 50	37° = 100	25-32° = 100	200	200
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
200	200	200	100	0	1450/1800

FAILURE DETAILS:

Loading rate Loading rate not considered to be a factor of instability.

Monitoring Monitoring data not available prior to event, however observations of dump crest 12 hours prior to failure include a series of steps 1 m deep each.

Climate Data Heavy rains (9 mm) on morning of failure event.

Indicated Mode Rotational slump within dump material.

Indicated Cause Increased pore pressure within the dump itself; high fines content; captured snow adding to moisture; foundation seepage zone in natural gully; oversteepening of crest; steep foundation especially in toe region.

DISCUSSION

Rotational failures within dump material occur in relatively homogeneous embankments as a result of elevated pore pressure causing a reduction in shear strength of the material. This dump contained a percentage of fine grained poor quality material and could not be regarded as being free draining. The slip surface was observed to be completely lined with fine material after the failure.

In addition snow and ice lenses were observed in the material, which were buried during winter construction. Surface drainage from the mine was inadequately controlled, and runoff from the platform itself was directed to the failed area. The failed area coincided with the location of a natural gully, and seepage pressures may have been high here. The foundation slopes are steep and unconfined at the toe and the foundation conditions do not appear to have influenced this failure.

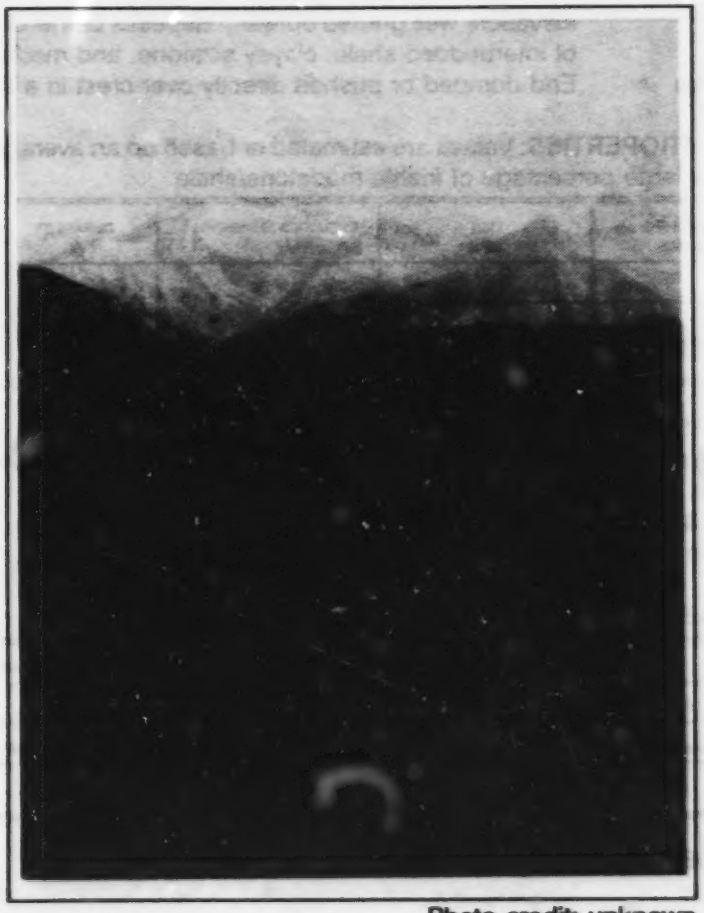


Photo credit: unknown

Photograph 1: Record 29 dump failure.

MINE DUMP FAILURE SUMMARY

RECORD NO. 30

MINE: E - Open pit coal
DUMP NAME: G - Active at time of failure.
DATE OF FAILURE: April 24-26, 1981
DUMP HEIGHT: Approx. 20 m
FAILURE VOLUME: 80,000 m^3 dump material, 250,000 m^3 foundation soils
RUNOUT DIST.: Exhibited heaving of natural soils below dump toe instead of large displacement.

GENERAL DATA:

Topography Creek valley sloping up to 10°, linear in profile.
Geometry Unconfined sidehill fill, linear shape.
Foundation Normally consolidated, stratified clay and silt with fine sand partings, unknown depth to bedrock, natural moisture content 21.4-22.9%, average liquid limit of 28.3%, and plastic limit of 14.8%, shear strengths tested 50-150 kPa making these soils stiff to very stiff.
Construction End dumped and pushed in single lift to maximum lift height.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests. A large quantity of overburden soils, probably saturated, were also placed at this site.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH $\phi'(°)$, c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	<#200
SHALE est.(70%)	10-50	37°, 0	LOW	40	5

DESIGN ASSUMPTIONS:

Material Strengths Dump ϕ'= 37°, c'=0, Foundation material (gravel) ϕ'= 35°, c'=0, Clay S_u=100 kPa
Piezometric Assumptions Undrained shear strength for clay assumed
Method of Stability Calculation Janbu, Morgenstern-Price
Design Safety Factor ~ 1.0 (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
>50 m = 0	>1 Mm^3 = 0	<26° = 0	<10° = 0	50	200
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
200	0	200	0	0	650/1800

FAILURE DETAILS:

Loading rate Loading rate not considered a factor of instability.
Monitoring No monitoring data available.
Climate Data Onset of spring melt prior to failure.
Indicated Mode Slumping in dump material was rotational, in foundation was translational.
Indicated Cause Increased foundation pore pressure due to groundwater recharge; increased load due to saturation of fines in dump.

DISCUSSION

The dump was composed mostly of excavated soils from the mine site, mostly silt and clay size particles, and low durability shale. The material created what was recognised as a relatively impermeable fill. The dump toe was a relatively large distance away from the creek bed. The natural soils which are extensive in the area adjacent to the creek are very fine lacustrine clays and silts with some sand partings. The sand can act as a conduit if continuous to boundaries.

The failure occurred during a period of groundwater recharge due to spring runoff and precipitation. The recharge may have influenced the pore pressures within the foundation soils, especially within the sand partings. As the load of the dump increased due to loading and the increased material weight due to added moisture content, the sand partings within the foundation liquefied causing local instability. The instability rapidly increased in area as high pore pressures were carried by the sand conduit(s) due to the sudden loading caused by the initial failure.

Observations of the resulting debris indicate a series of rotational scarps through the fine grained dump material, and translational sliding on a very shallow plane, as evident by the tilting of trees. The resulting heave or uplift of 3-4 m at the creek bed was caused by these movements. The area of influence at the toe of the original dump was 200 m in length.

MINE DUMP FAILURE SUMMARY — RECORD NO. 31

MINE: E - Open pit coal
DUMP NAME: G - Active at time of failure.
DATE OF FAILURE: May 23, 1988
DUMP HEIGHT: Approx. 20 m
FAILURE VOLUME: 60,000 m^3 waste soil, 170,000 m^3 foundation soils
RUNOUT DIST.: Exhibited heaving of natural soils below dump toe instead of large displacement.

GENERAL DATA:

Topography Creek valley sloping up to 10°, linear in profile.
Geometry Unconfined sidehill fill, linear shape
Foundation Normally consolidated, stratified clay and silt with fine sand partings, unknown depth to bedrock, natural moisture content 21.4-22.9%, average liquid limit of 28.3%, and plastic limit of 14.8%, shear strengths tested 50-150 kPa making these soils stiff to very stiff.
Construction End dumped and pushed in single lift to maximum lift height.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests. A large quantity of overburden soils, probably saturated, were also placed at this site.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH $\phi'(°)$, c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >300mm	<#200
SHALE est.(70%)	10-50	37°, 0	LOW	40	5

DESIGN ASSUMPTIONS:

Material Strengths Clay S_u = 70 kPa, sand and gravels ϕ'=32°, c'=0
Piezometric Assumptions Undrained shear strength for clay assumed
Method of Stability Calculation Janbu, Morgenstern-Price
Design Safety Factor For ultimate dump 1.0-1.1

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
>50 m = 0	>1 Mm^3 = 0	<26° = 0	<10° = 0	80	200
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
200	0	200	0	0	650/1800

FAILURE DETAILS:

Loading rate Loading rate not considered a factor of instability.
Monitoring No monitoring data available.
Climate Data Spring melt.
Indicated Mode Slumping in dump material was rotational, in foundation was translational.
Indicated Cause Increased foundation pore pressure due to groundwater recharge; saturated fines in dump.

DISCUSSION

Similar event on this dump occurred in 1981. The dump was composed of excavated soils from the mine site, mostly silt and clay size particles, and low durability shale. The material created what was recognised as a relatively impermeable fill. The dump toe was a relatively large distance away from the creek bed. The natural soils which are extensive in the area adjacent to the creek are very fine lacustrine clays and silts with some sand partings. The sand can act as a conduit if continuous to boundaries.

The failure occurred during a period of groundwater recharge due to spring runoff and precipitation. The recharge may have influenced the pore pressures within the foundation soils, especially within the sand partings. As the load of the dump increased due to loading and the increased material weight due to added moisture content, the sand partings within the foundation liquefied causing local instability. The instability rapidly increased in area as high pore pressures were carried by the sand conduit(s) due to the sudden loading caused by the initial failure.

Observations of the resulting debris indicate a series of rotational scarps through the fine grained dump material, and translational sliding on a very shallow plane, as evident by the tilting of trees. The resulting heave or uplift of 0.5 m at the creek bed was caused by these movements. The area of influence at the toe of the original dump was 130 m in length.

MINE DUMP FAILURE SUMMARY — RECORD NO. 32

MINE: F - Open pit coal
DUMP NAME: A - Active at time of failure.
DATE OF FAILURE: August 16, 1987
DUMP HEIGHT: 175 m (crest at elev. 1615 m, toe at elev. 1440 m)
FAILURE VOLUME: 100,000 m^3
RUNOUT DIST.: 250 m

GENERAL DATA:

Topography Concave downward in profile.
Geometry Unconfined sidehill wrap around, no 3D wedging effect.
Foundation Veneer of moderately dense coarse grained sandy gravel colluvium on highly fractured bedrock. Areas of foundation seepage observed. Areas of strong free-draining slide debris.
Construction End dumped or pushed directly over crest.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH $\phi'(\Omega)$, c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >100mm	<#200
SANDSTONE (50)	>103	37°,0	HIGH - V.HIGH	75	5
SILTSTONE (20)	83		MED - HIGH	60	15
MUDSTONE (30)	7-34		V.LOW - LOW	40	20

DESIGN ASSUMPTIONS:

Material Strengths Dump $\phi'=37°$, $c'=0$; Foundation $\phi'=33°$, $c'=0$
Piezometric Assumptions Drained (see legend)
Method of Stability Calculation Janbu
Design Safety Factor ~1.2 (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
100-200 m = 100	1-50 Mm^3 = 50	37° = 100	25-32° = 100	100	100
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
200	200	200	200	0	1350/1800

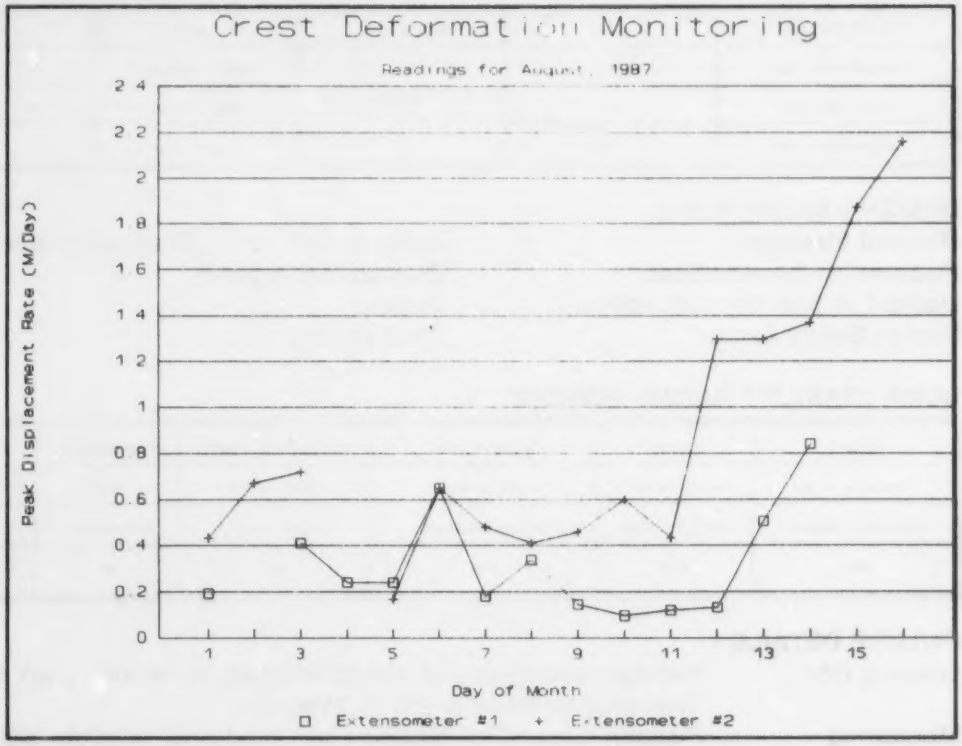
FAILURE DETAILS:

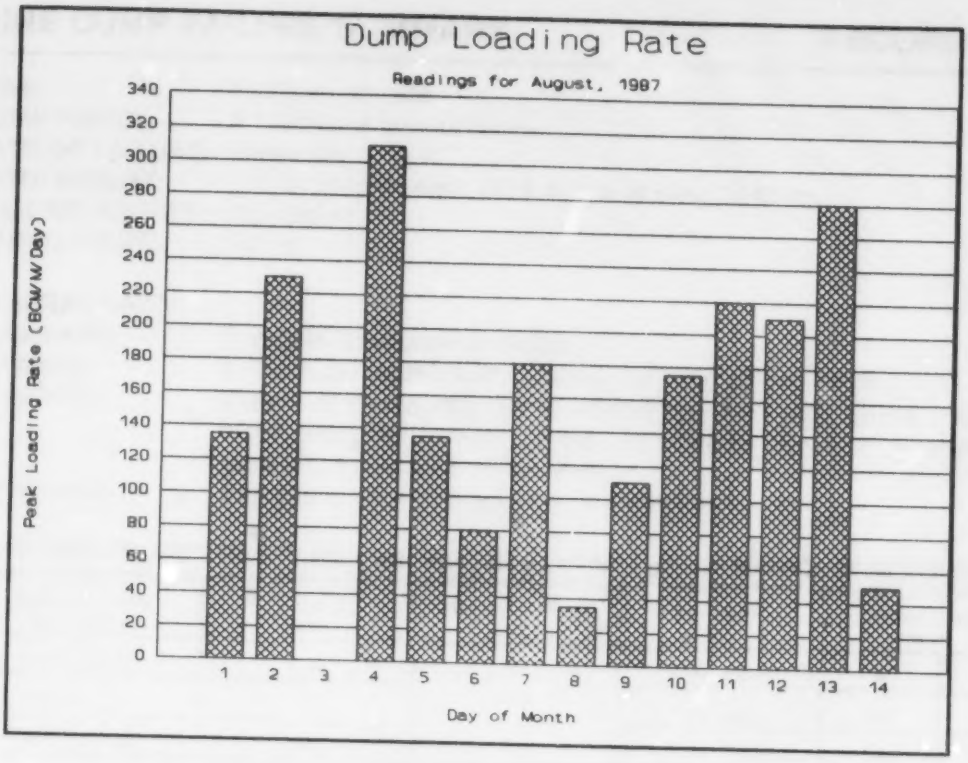
Loading rate Average loading rate of 100 BCM/m/day for month, peak loading rate 3 days prior to failure of 280 BCM/m/hr.
Monitoring Platform deformation observed well in advance of failure, with up to 4 cm/h across failure plane 4 days prior to failure.
Climate Data Intense and prolonged rain storms for preceding week with significant rainfall.
Indicated Mode Slow and gradual plane failure along plane of weakness within dump material.
Indicated Cause Loading rate; pore pressure in foundation due to redistribution of stress; rain water infiltration into dump; seepage pressure at toe area due to groundwater recharge.

DISCUSSION

The dump contained good to fair quality rock and was observed to be dry before and after the failure, indicating the material capacity for draining and therefore its quality. Intense rains were recorded for the previous week causing infiltration of water into the dump and increased foundation seepage pressure. Increasing the water level within the dump reduced the shear strength of the material, especially along the foundation contact, but also along planes of weakness of captured snow or fines. Loading rates for the dump which were recorded on an hourly basis and when converted to load per day indicated very high rates. Rapid construction is associated with the amount and rate of strain observed.

The failure was preceded by the movement of the platform and the development of a bulge 2 days prior to failure. These deformations indicate the redistribution of stresses within the dump imposing increased load on lower slopes. Increased loading and the generation of pore pressure within the foundation or at the dump toe is consistent with the observation of the failure being slow and gentle where the crest and monitor stands moved downslope intact. The mechanism for this event included slowly yielding toe material causing a loss of support for the dump slope above, and slow failure along planes of weakness.




Dump Loading Rate
Readings for August, 1987
Peak Loading Rate (BCW/W/Day)
340
320
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
Day of Month

MINE DUMP FAILURE SUMMARY — RECORD NO. 33

MINE: F - Open pit coal
DUMP NAME: A - Active at time of failure.
DATE OF FAILURE: December 5, 1987
DUMP HEIGHT: 175 m (crest at elev. 1615 m, toe at elev. 1440 m).
FAILURE VOLUME: 200,000 m^3
RUNOUT DIST.: 100 m

GENERAL DATA:

Topography Concave downward in profile.
Geometry Unconfined sidehill wrap around, no 3D wedging effect.
Foundation Veneer of moderately dense coarse grained sandy gravel colluvium on highly fractured bedrock. Areas of foundation seepage observed. Areas of strong free-draining slide debris.
Construction End dumped or pushed directly over crest.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH $\phi'(^\circ)$, c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >100mm	PARTICLE SIZE (%) <#200
SANDSTONE (50)	>103	37°,0	HIGH - V.HIGH	75	5
SILTSTONE (20)	83		MED - HIGH	60	15
MUDSTONE (30)	7-34		V.LOW - LOW	40	20

DESIGN ASSUMPTIONS:

Material Strengths Dump $\phi'=37°$, $c'=0$; Foundation $\phi'=33°$, $c'=0$
Piezometric Assumptions Drained (see legend)
Method of Stability Calculation Janbu
Design Safety Factor ~1.2 (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
100-200 m = 100	1-50 Mm^3 = 50	37° = 100	25-32° = 100	100	100
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
200	200	200	200	0	1350/1800

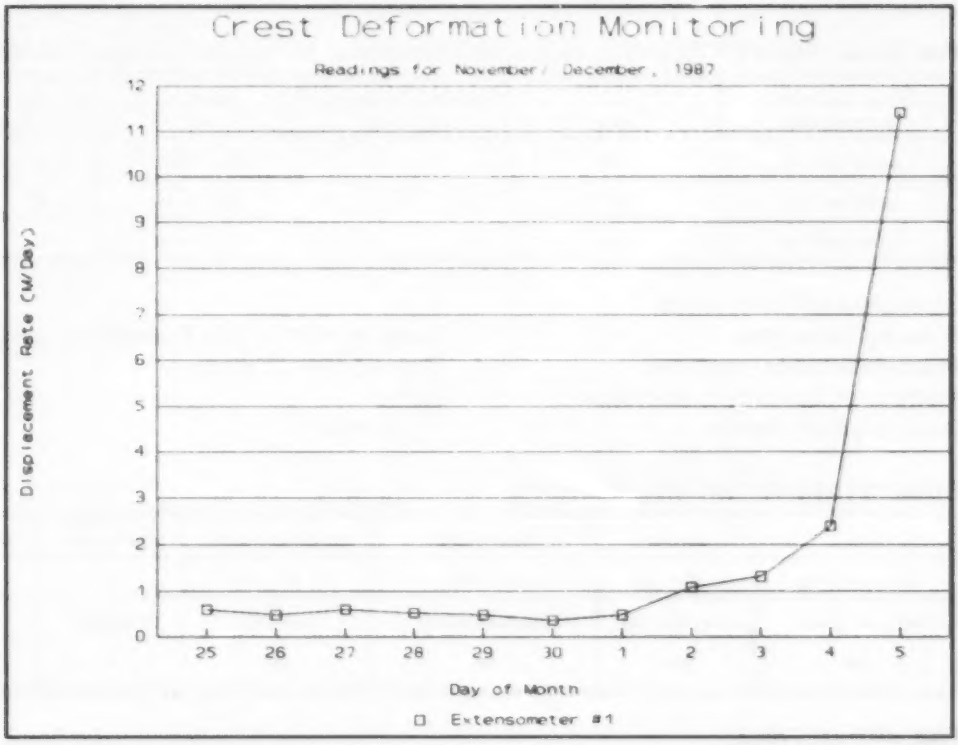
FAILURE DETAILS:

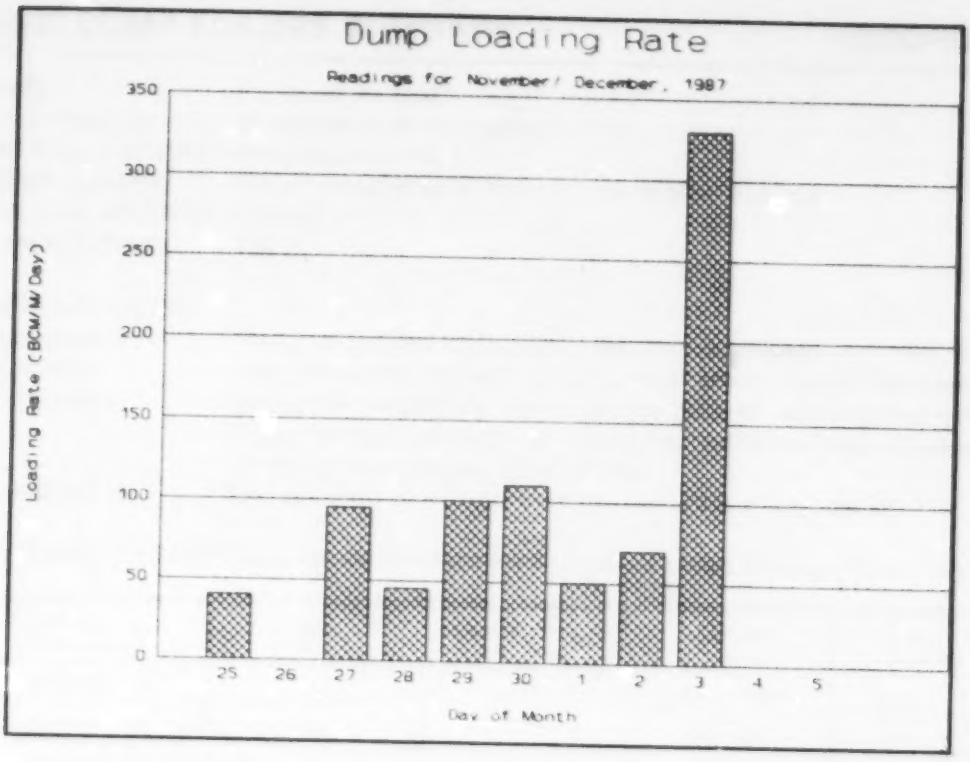
Loading rate 2 days prior to failure equivalent peak loading rate of 550 BCM/m/day, average loading rate for month was ~100 BCM/m/day.
Monitoring Crest deformation rates of 10 cm/h up to 3 days prior to failure.
Climate Data Precipitation not considered a factor of instability.
Indicated Mode Creeping plane failure.
Indicated Cause High loading rate causing the generation of pore pressure; thick zone of saturated fines at dump face; loading remnant bulge of previous failure plane.

DISCUSSION

The dump experienced a previous failure on August 16, 1987. During that event high loading rates and precipitation had induced the development of a face bulge. At the time of that failure the material appeared to be of good quality and did not appear wet in spite of the rainfall infiltration. During the intervening time a remnant bulge of the August failure was observed although no record of any increase in size was made. Inspection of the bulge found it to be composed of a 4 to 6 m thick layer of fine grained material with water seepage exiting from the material.

Loading of the dump face and remnant bulge occurred at a reasonable rate up to 2 days prior to failure when peak rates in excess of 550 BCM/m/day were recorded. High loading rate of the remnant bulge and foundation caused the generation of pore pressure in excess of dissipation leading to a reduction in shear strength. This mechanism is consistent with the observed slow and "gentle" failure where the crest and monitor stand moved downslope relatively intact.




Dump Loading Rate
Readings for November / December, 1987
Loading Rate (BCM/M/Day)
350
300
250
200
150
100
50
0
25
26
27
28
29
30
1
2
3
4
5
Day of Month

MINE DUMP FAILURE SUMMARY — RECORD NO. 34

MINE: F - Open pit coal
DUMP NAME: B - Active at time of failure.
DATE OF FAILURE: September 7, 1988
DUMP HEIGHT: 190 m (crest at elev. 1630 m, toe at elev. 1440 m)
FAILURE VOLUME: 450,000 m^3
RUNOUT DIST.: 100 m

GENERAL DATA:

Topography Steep underlying topography, concave downward in profile.
Geometry Unconfined sidehill wrap around, wrap around bench for upper dumps.
Foundation Veneer of moderately dense coarse grained sandy gravel colluvium on highly fractured bedrock. Areas of foundation seepage observed. Areas of strong free-draining slide debris.
Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH $\phi'(^\circ)$, c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >100 mm	<#200
SANDSTONE (50)	>103	37°, 0	HIGH - V.HIGH	75	5
SILTSTONE (20)	83		MED - HIGH	60	15
MUDSTONE (30)	7-34		V.LOW - LOW	40	20

DESIGN ASSUMPTIONS:

Material Strengths Dump ϕ'=37°, c'=0; Foundation ϕ'=33°, c'=0
Piezometric Assumptions Drained (see legend)
Method of Stability Calculation Janbu
Design Safety Factor ~1.2 (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
>200 m = 200	>50Mm³ = 100	37° = 180	25-32° = 100	100	100
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
200	200	100	100	50	1350/1800

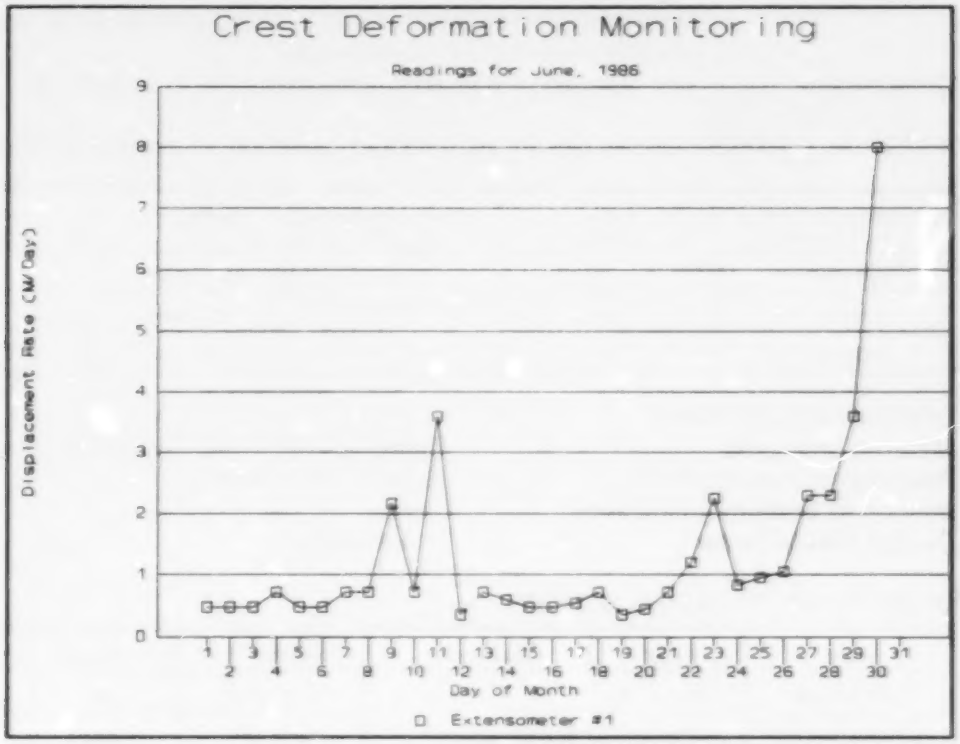
FAILURE DETAILS:

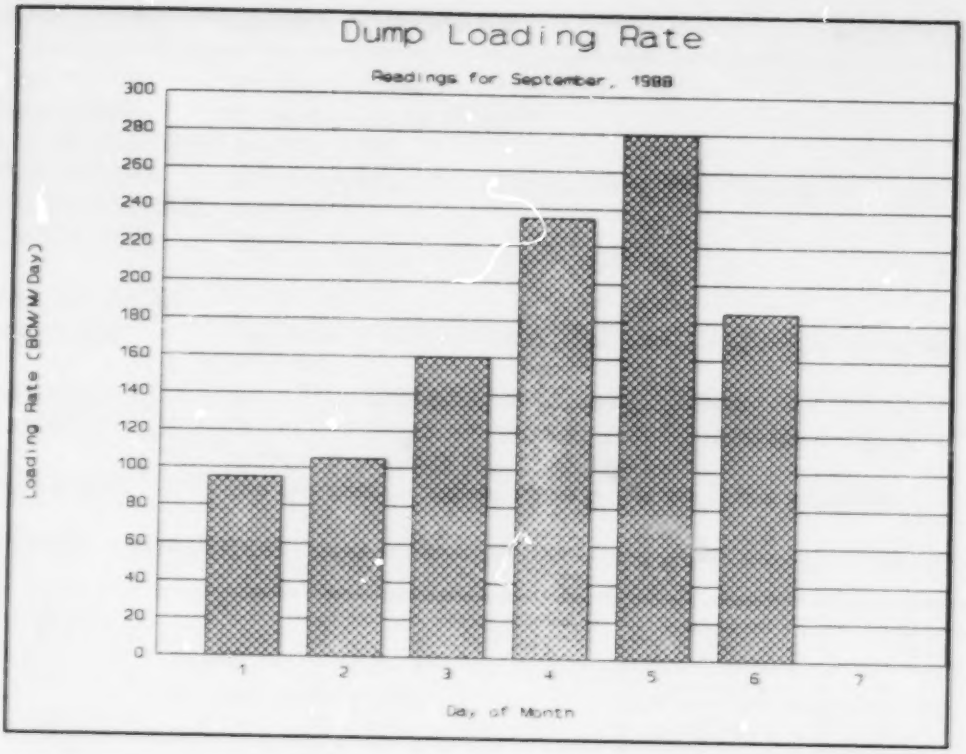
Loading rate Average loading rates for month prior to failure was 280 BCM/m/day.
Monitoring Crest deformation of 20 cm/h 7 hours prior to failure and 62 cm/h 5 hours prior to failure.
Climate Data Precipitation not considered a factor of instability.
Indicated Mode Sliver failure.
Indicated Cause Wet fine material placed on dump face 2 months previously; high loading rate; continued loading to maintain platform grade.

DISCUSSION

The dump consisted of a high percentage of fines and had a long history of deformation and failure related to loading rate and precipitation. Two months prior to failure a large quantity of wet fine grained material was placed and oversteepened at the crest causing a build up and oversteepening. During this time high deformation rates of 19 cm/h, attributed to intense rainfall, were observed and then stabilized, however major instability did not occur.

The failure was likely due to a combination of high loading rates and induced strain rate, and the accumulation of wet fine grained material causing oversteepening of the crest. The placement of an addition 15 m lift placed after initial "settlement" to maintain grade of the platform served to increase the load of the failure plane and further promoted instability.




Dump Loading Rate
Readings for September, 1988
Loading Rate (BCM/W/Day)
300
280
260
240
220
200
180
160
140
120
100
80
60
40
20
0
1
2
3
4
5
6
7
Day of Month

MINE DUMP FAILURE SUMMARY — RECORD NO. 35

MINE: F - Open pit coal
DUMP NAME: C - Active at time of failure.
DATE OF FAILURE: June 21, 1986
DUMP HEIGHT: 200 m (crest at elev. 1640 m, toe at elev. 1440 m)
FAILURE VOLUME: 450,000 m^3
RUNOUT DIST.: 300 m

GENERAL DATA:

Topography Toe slope = 15°; mid slope = 30°; crest slope = 20°; concave downward in profile.

Geometry unconfined sidehill fill, no 3D wedging effect.

Foundation Bedrock outcrops with blanket of well graded sandy gravel colluvium, no springs or seepage points observed.

Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH $\phi'(°)$, $c'(kPa)$	DURABILITY (%)	PARTICLE SIZE (%) >100mm	<#200
SANDSTONE (50)	>103	37°, 0	HIGH - V.HIGH	75	5
SILTSTONE (20)	83		MED - HIGH	60	15
MUDSTONE (30)	7-34		V.LOW - LOW	40	20

DESIGN ASSUMPTIONS:

Material Strengths Dump $\phi'=37°$, $c'=0$; Foundation $\phi'=33°$, $c'=0$

Piezometric Assumptions Drained (see legend)

Method of Stability Calculation Janbu, Double Wedge

Design Safety Factor ~ 1.2 (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
100-200 m = 100	1-50 Mm^3 = 50	37° = 100	25-32° = 100	100	100
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
100	200	200	200	0	1250/1800

FAILURE DETAILS:

Loading rate The average loading rate prior to failure was 160 BCM/m/day with peak loading rates preceding failure of 390 BCM/m/day.

Monitoring Visual records of crest dropping approximately 1 m/h hours before failure.

Climate Data Heavy rain prior to failure causing infiltration and perhaps foundation seepage pressure by groundwater recharge (although not reported in foundation investigation).

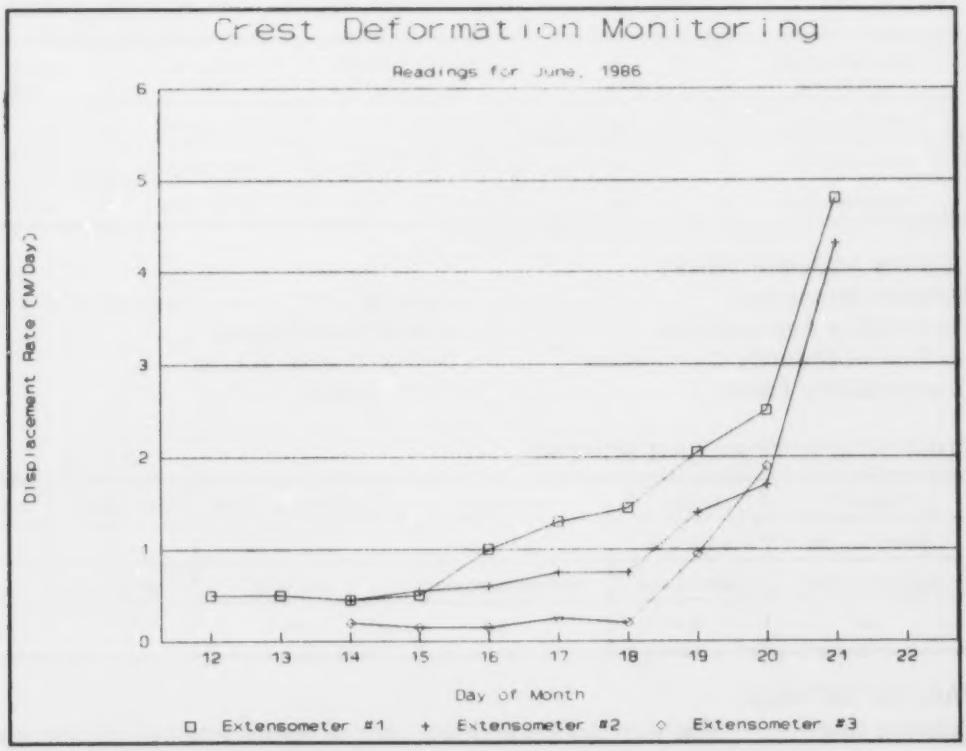
Indicated Mode Toe failure causing loss of support for mass above and planar failure along a plane of weakness within the dump.

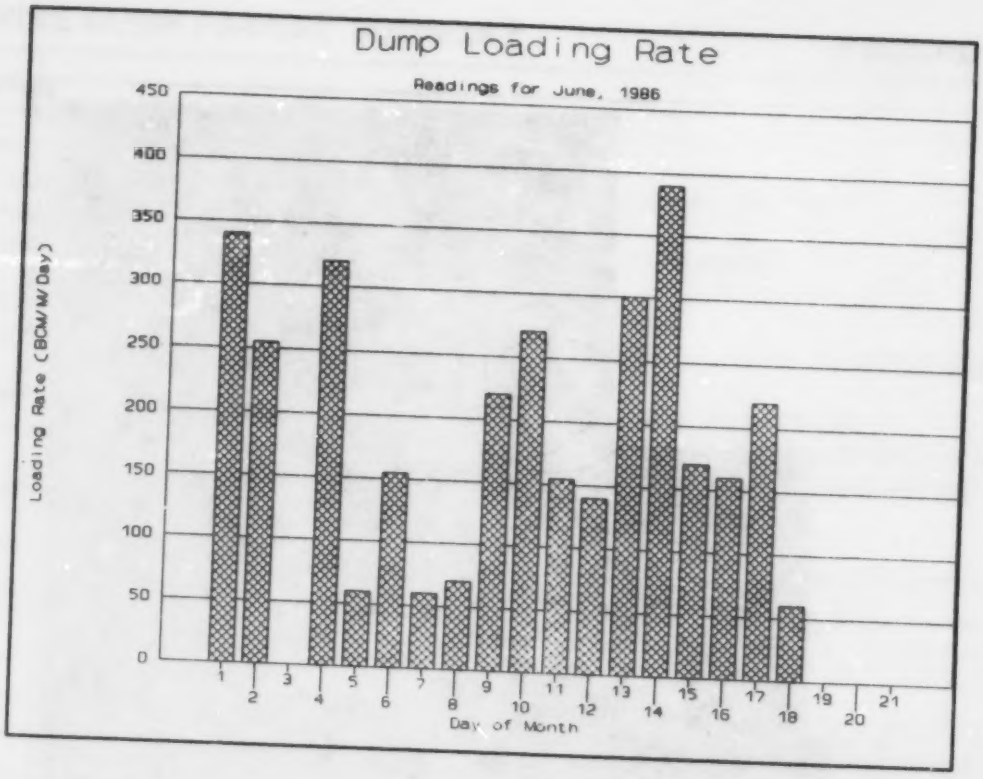
Indicated Cause High loading rate and a history of large strain deformation; high precipitation; redistribution of dump stresses causing rapid loading of foundation and the generation of pore pressure.

DISCUSSION

The dump contained good to fair quality rock and was observed to be dry before and after the failure, indicating the material capacity for draining and therefore its quality. Fines were contained in the dump but were well mixed with competent sandstone boulders. Intense rains were recorded for the previous week causing infiltration of water into the dump and increased foundation seepage pressure. Increasing the water level within the dump reduced the shear strength of the material, especially along the foundation contact, but also along planes of weakness of captured snow or fines. Loading rates for the dump were recorded on an hourly basis and when converted to load per day indicated very high rates. Rapid construction was associated with the amount and rate of strain observed.

The failure was preceded by the movement of the platform and extensive bulging at the toe prior to failure. These deformations indicate the redistribution of stresses within the dump imposing increased load on lower slopes. The mechanism for this event included slowly yielding toe material causing a loss of support for the dump slope above, and slow failure along planes of weakness.




Dump Loading Rate
Readings for June, 1986
Loading Rate (BCM/HW Day)
450
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
Day of Month

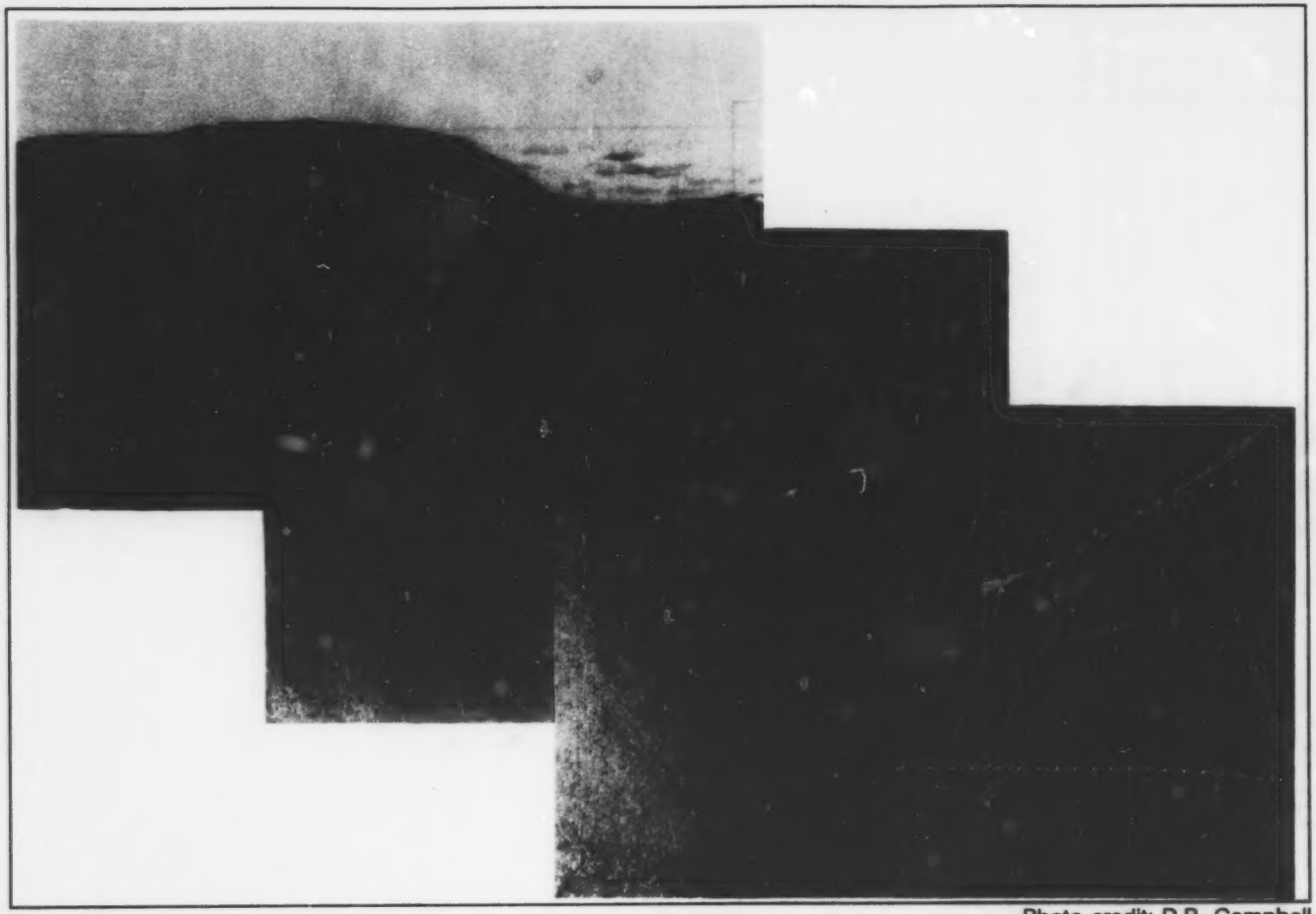


Photo credit: D.B. Campbell

Photograph 1: Record 35 dump failure.

MINE DUMP FAILURE SUMMARY — RECORD NO. 36

MINE: F - Open pit coal
DUMP NAME: D - Inactive
DATE OF FAILURE: September 9, 1985
DUMP HEIGHT: 220 m (crest at elev. 1660 m, toe at elev. 1440 m)
FAILURE VOLUME: $3x10^6$ m^3
RUNOUT DIST.: 2000 m (average 15° runout slope - mudflow)

GENERAL DATA:

Topography Toe slope 18-20°; mid slope = 39°; no natural foundation slope above elevation 1520 m.

Geometry Unconfined sidehill fill, wrap around for upper dumps.

Foundation Directly on folded and highly fractured sedimentary bedrock or on veneer of colluvial soils. Colluvium is coarse grained and not very extensive.

Construction End dumped or pushed directly over crest.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH φ'(°), c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >100mm	PARTICLE SIZE (%) <#200
SANDSTONE (50)	>103	37°, 0	HIGH - V.HIGH	75	5
SILTSTONE (20)	83		MED - HIGH	60	15
MUDSTONE (30)	7-34		V.LOW - LOW	40	20

DESIGN ASSUMPTIONS:

Material Strengths Dump $\phi'=37°$, $c'=0$; Foundation $\phi'=33°$, $c'=0$

Piezometric Assumptions Drained (see legend)

Method of Stability Calculation Janbu

Design Safety Factor ~1.2 (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
>200 m = 200	1-50 Mm^3 = 50	37° = 100	25-32° = 100	100	200
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
200	200	200	100	0	1350/1800

FAILURE DETAILS:

Loading rate Loading rates of 80 BCM/m/day in vicinity of failure but only loaded sporadically. Loading in adjacent areas of up to 180 BCM/m/day.

Monitoring Monitor data unreliable.

Climate Data Heavy rainfall prior to failure (45 mm) resulting in infiltration and groundwater recharge causing foundation seepage pressure.

Indicated Mode Rotational toe failure causing loss of support for mass above and failure along a plane of weakness within dump.

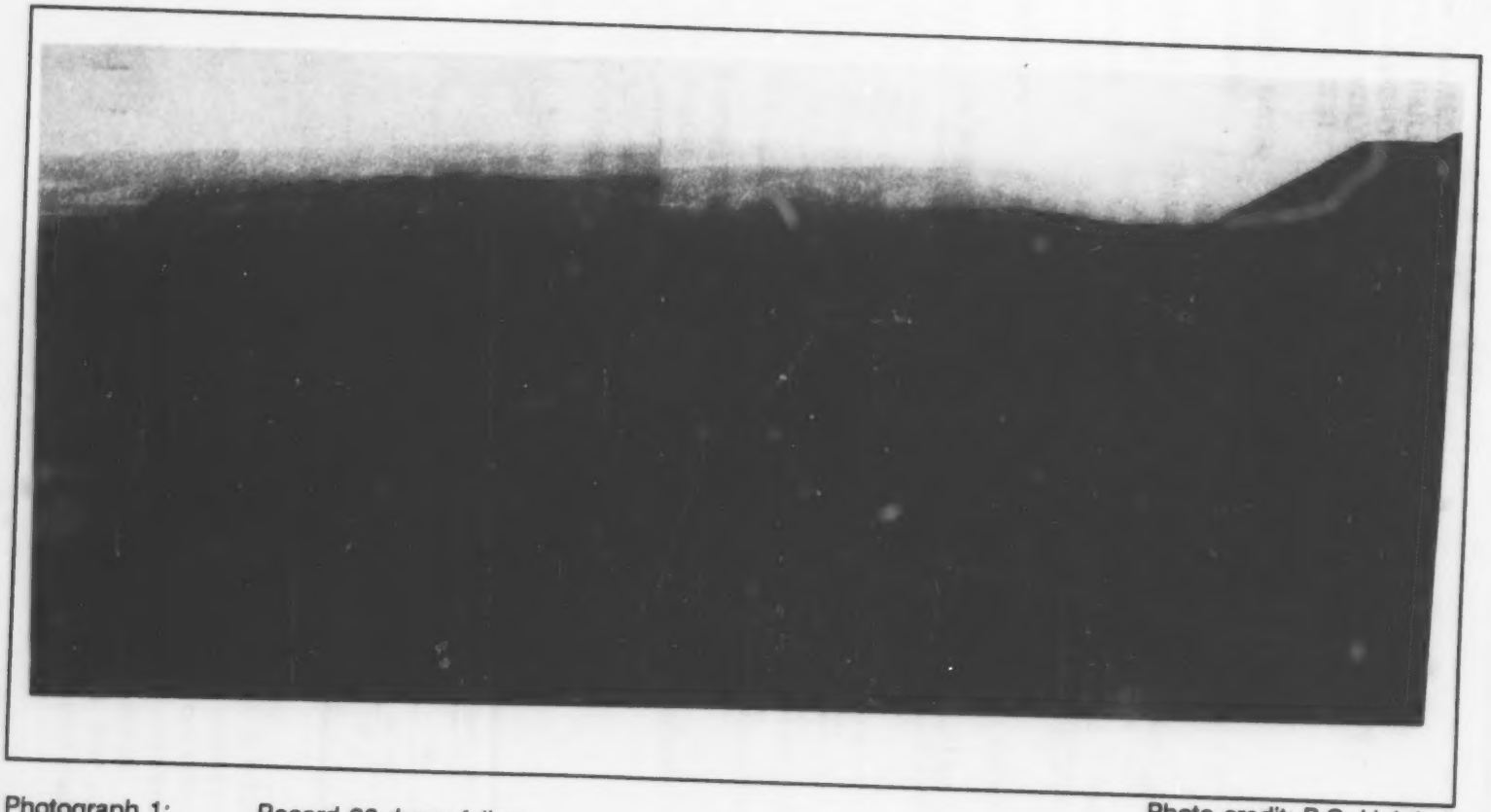
Indicated Cause Elevated dump pore pressure due to infiltration; snow contained in dump forming a continuous weak plane; wet fine material; foundation seepage pressure; dump height.

DISCUSSION

The high dump was characterized by steep foundation slopes and areas of poor foundation material and seepage pressure. The dump had become recently oversteepened due to the presence of wet fine grained material and a large quantity of degradable carbonaceous mudstone. The mine rock contained a high percentage of fines due to intensive blasting practises. Prior to the failure little dumping had actually occurred in the area; a total of 50,000 BCM for all of August. Much of the dump construction had taken place during winter and a large amount of snow was captured and insulated during this time. Snow contained in dumps generally remains intact until warm rainwater can cause it to melt. During the dry summer there were few opportunities for this to happen and the snow probably remained frozen.

No major cracking or bulging was evident prior to failure, indicating a rather sudden reduction in shear strength. This is consistent with the observations of a rapidly accelerating movement causing large scale scouring of natural till and boulders.

The failure travelled a substantial distance downslope causing damage to a powerline and sedimentation pond below.



Photograph 1: Record 36 dump failure

Photo credit: P.C. Lighthall

MINE DUMP FAILURE SUMMARY — RECORD NO. 37

MINE: F - Open pit coal
DUMP NAME: E - Active at time of failure.
DATE OF FAILURE: August 17, 1984
DUMP HEIGHT: 250 m (crest at elev. 1690 m, toe at elev. 1440 m)
FAILURE VOLUME: 1.5×10^6 m³
RUNOUT DIST.: 300 m (average 12° runout slope)

GENERAL DATA:

Topography Toe slope = 22°; mid slope = 30°; crest slope = 32°; concave downward in profile.

Geometry Unconfined sidehill fill, wrap around for upper dumps, no 3D wedging effect.

Foundation Veneer of moderately dense coarse grained colluvium over bedrock. Highly fractured bedrock below, seepage points observed during periods of recharge.

Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH ϕ (), c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >100mm	PARTICLE SIZE (%) <#200
SANDSTONE (50)	>103	37°, 0	HIGH - V HIGH	75	5
SILTSTONE (20)	83		MED - HIGH	60	15
MUDSTONE (30)	7-34		V LOW - LOW	40	20

DESIGN ASSUMPTIONS:

Material Strengths Dump ϕ'=37°, c'=0; Foundation ϕ'=32-35°, c'=0
Piezometric Assumptions Drained (see legend)
Method of Stability Calculation Janbu
Design Safety Factor ~ 1.2 (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
>200 m = 200	1-50 Mm³ = 50	37° = 100	25-32° = 100	100	100
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
200	200	200	200	0	1450/1800

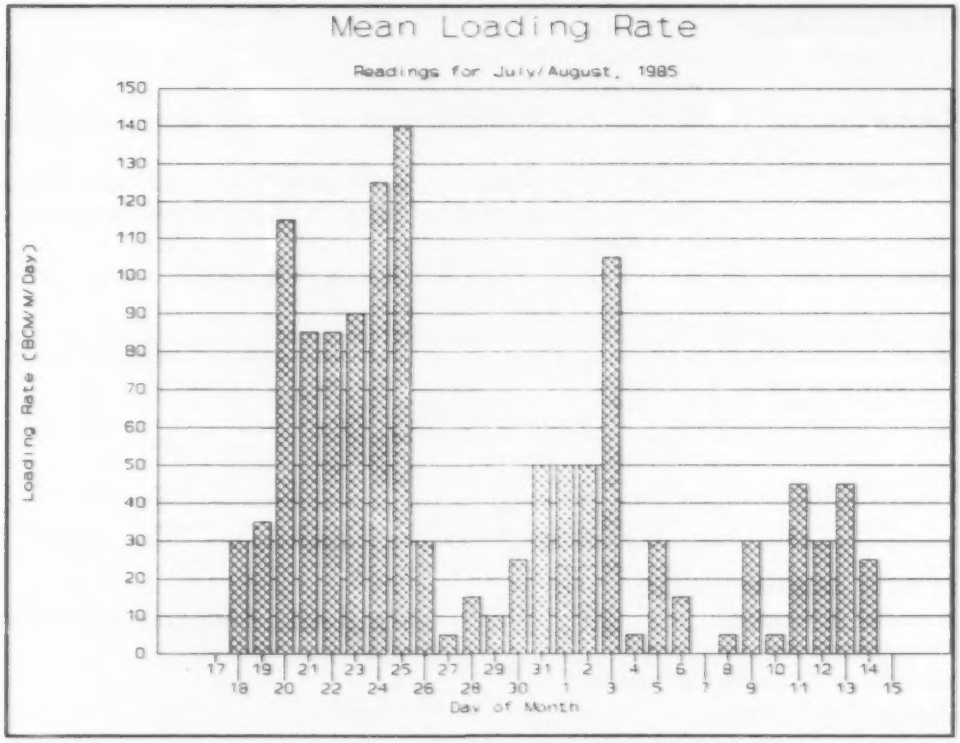
FAILURE DETAILS:

Loading rate Loading rate in excess of 130 BCM/m/day prior to failure.
Monitoring Visual records of up to 3 cm/h across tension cracks prior to failure.
Climate Data Total precipitation of 27 mm for August 5-15; not considered a principle factor of instability but added moisture to fines and increased unit weight.
Indicated Mode Series of 3-4 rotational failures within dump material.
Indicated Cause High percentage wet fine grained material and readily degradable carbonaceous mudstone; large strains due to rapid loading; dump height.

DISCUSSION

Dumping at this site included the placement of a large quantity of fine and readily degradable rock. Precipitation may have raised the moisture content of the material causing an increase in unit weight and thereby increasing the load on potential failure planes.

The failure occurred within the dump material only and had the form of several rotational slides, consistent with the homogeneous nature of the fine grained material.



MINE DUMP FAILURE SUMMARY

RECORD NO. 38

MINE: F - Open pit coal
DUMP NAME: E - Active at time of failure.
DATE OF FAILURE: October 4, 1985
DUMP HEIGHT: 250 m
FAILURE VOLUME: 2.2×10^6 m^3
RUNOUT DIST.: 1200 m

GENERAL DATA:

Topography Toe slope = 22°; mid slope = 30°; crest slope = 32°; concave downward in profile.

Geometry Unconfined sidehill fill, wrap around for upper dumps.

Foundation Veneer of moderately dense coarse grained colluvium over bedrock. Highly fractured bedrock below, springs observed during recharge.

Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH ϕ'(°), c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >100mm	<#200
SANDSTONE (50)	>103	37°, 0	HIGH - V.HIGH	75	5
SILTSTONE (20)	83		MED - HIGH	60	15
MUDSTONE (30)	7-34		V.LOW - LOW	40	20

DESIGN ASSUMPTIONS:

Material Strengths Dump ϕ'=37°, c'=0; Foundation ϕ'=32-35°, c'=0

Piezometric Assumptions Drained (see legend)

Method of Stability Calculation Janbu

Design Safety Factor ~ 1.2 (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
>200 m = 200	1-50 Mm^3 = 50	37° = 100	25-32° = 100	100	100
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
200	200	200	100	0	1350/1800

FAILURE DETAILS:

Loading rate Average loading rates for August and September are 50 BCM/m/day and 70 BCM/m/day respectively. Peak loading rate of 115 BCM/m/day several days prior to failure.

Monitoring Crest deformation peak rate of 7 cm/h for August 1, and 5 cm/h September 27.

Climate Data Heavy precipitation in previous August and September, 93 mm and 107 mm respectively, causing infiltration and groundwater recharge.

Indicated Mode Rotational slump of toe material causing loss of support for mass above and planar sliding along weak plane.

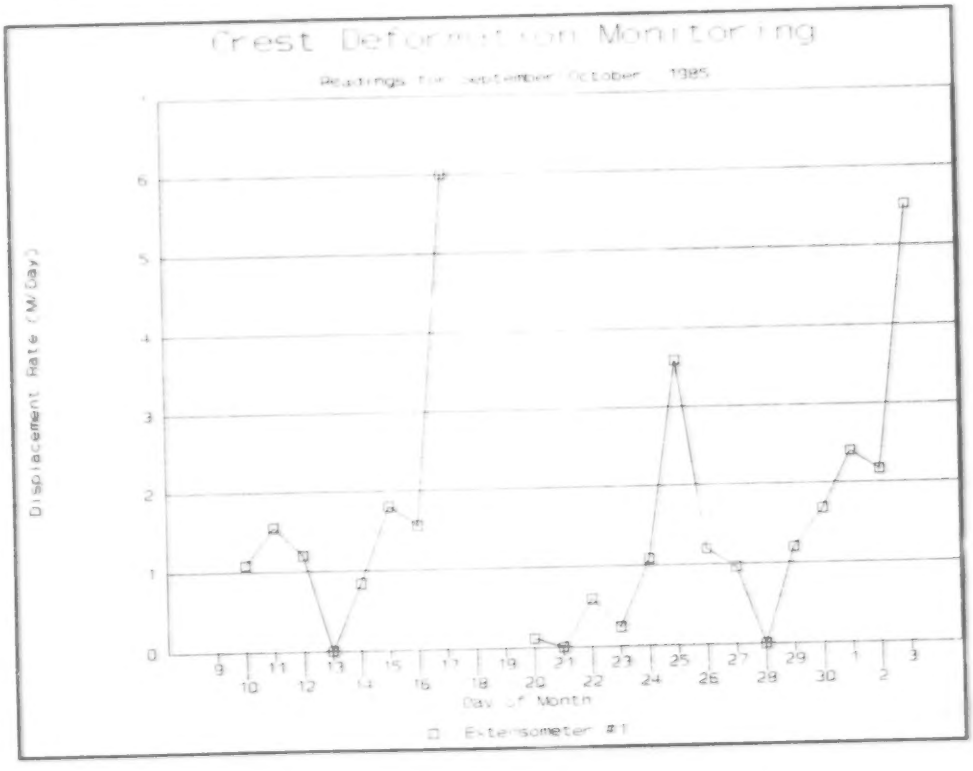
Indicated Cause Large percentage fines; internal pore pressure caused by melting snow/ice within dump; continuous layer of snow along winter construction slope.

DISCUSSION

Similar failure occurred on same dump in August 1984. The dump had significant winter construction including poor quality fines and a large quantity of snow capture. Snow was also dumped off the platform during high snowfall events. Foundation conditions, including the presence of slide debris from the 1984 failure were reported as being sufficiently coarse to be free draining. Loading rates for the previous months were not unusually high, however loading during winter combined with snow and poor quality material likely caused the failure.

The failure was characterized by a 200 m high backscarp, most of which was at a slope of 35°, although it was steeper in some areas. This angle is consistent with the sliding mechanism along a weak plane defined by the winter construction slope composed of fines and snow. Bulging in the vicinity of the 1984 failure was recorded 11 days prior to failure, indicating a redistribution of stresses and higher loads imposed on the toe region. Once the toe failed the remaining mass became unsupported.

Three small creeks are evident below the dump, all of which join at the vicinity of the dump toe. These could act as a focus for drainage and could cause increased pore pressure within the dump toe as infiltration, melting snow and ice, and foundation seepage drain through and along the dump foundation contact.



MINE DUMP FAILURE SUMMARY — RECORD NO. 39

MINE: F - Open pit coal
DUMP NAME: F - Active at time of failure.
DATE OF FAILURE: March 13, 1990
DUMP HEIGHT: 25 m
FAILURE VOLUME: 210,000 m^3 (dump), 140,000 m^3 (foundation)
RUNOUT DIST.: N/A

GENERAL DATA:

Topography Gently sloping floodplain of large river, average slope 2.5°-3.5°.
Geometry Benched, lift construction, linear in plan.
Foundation Fluvial sand and gravel overlying thick normally consolidated lacustrine clay-silt. Thin (2-20 mm) sand layers within clay-silt.
Construction 15 m benches, 5 m construction lifts dumped over crest or on platform and levelled by dozer.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests. Approximately 20% of dump material was overburden soil placed by contractor.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH $\phi'(°)$, c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >100mm	<#200
SANDSTONE (50)	>103	37°, 0	HIGH - V.HIGH	75	5
SILTSTONE (20)	83		MED. - HIGH	60	15
MUDSTONE (30)	7-34		V.LOW - LOW	40	20

DESIGN ASSUMPTIONS:

Material Strengths Dump $\phi'=37°$, $c'=0$; Foundation $\phi'=33°$, $c'=0$; sand + gravel $\phi' = 30°$, silt S_u = 60-250 kPa
Piezometric Assumptions Undrained shear strength.
Method of Stability Calculation Sarma - circular and translational.
Design Safety Factor 1.3 (static).

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
>50 m = 0	1-50Mm³ = 50	28° = 0	<10° = 0	50	200
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
100	0	200	100	0	**700**/1800

FAILURE DETAILS:

Loading rate
Monitoring Pore pressure monitoring by piezometer, limit of 10 kPa/24 h response. In excess of 50 kPa increase during 10 day period before failure.
Climate Data From the end of February to March 6, the mean daily temperature was between 2 and 8°C, causing snow melt and groundwater recharge.
Indicated Mode Rotational - series of rotation slumps through dump and foundation.
Indicated Cause Strain induced pore pressure in clay-silt; poor pore pressure dissipation in clay-silt; groundwater recharge.

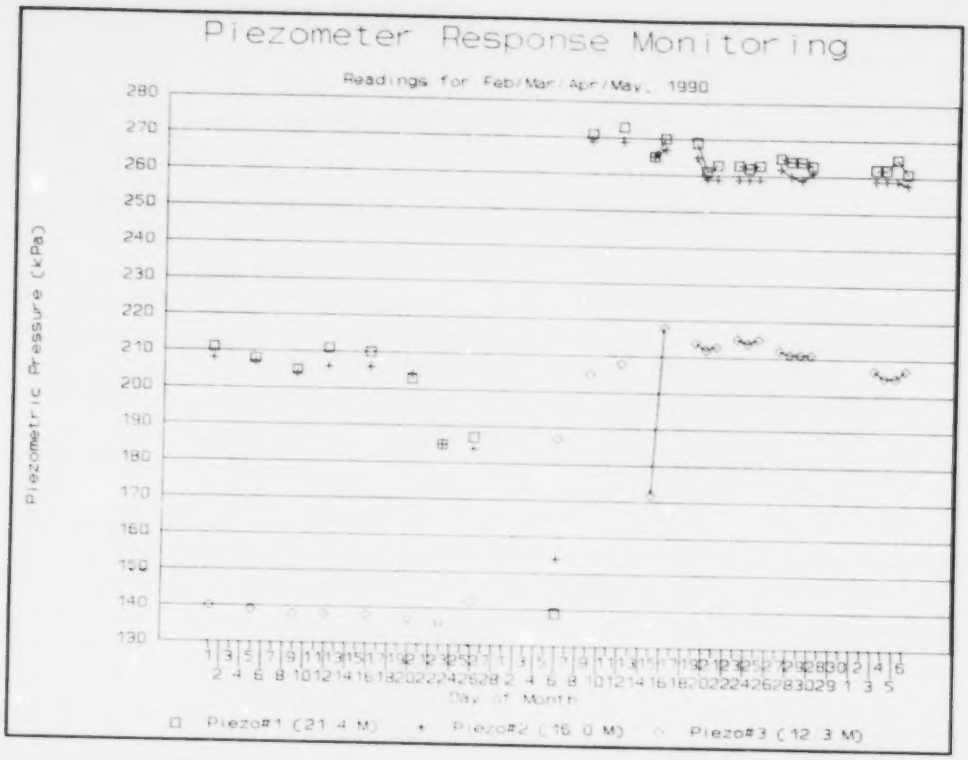
DISCUSSION

The small low level benched dump was constructed on a poor foundation consisting of lacustrine clay silt and sand partings. The clay silt was recognized as being weak and susceptible to pore pressure generation upon loading. The dump was to be constructed in 5 m construction lifts creating a bench or lift up to 15 m high, piezometric pressures were to be monitored during construction.

A warm period between February 28 and March 6 caused melting of snow and recharge, consistent with piezometer readings caused an increase of 5 kPa/day for the week. This was not enough change to exceed the design limits. On March 13 temperatures suddenly increased to a mean of 4°C after freezing mean temperatures for the intervening week. This rapid warming caused flow of meltwater again, and due to loading applied during the cold week piezometric pressures increased by 50 kPa. The new piezometric pressures were very close to causing liquefaction of the natural soils at this time. Failure finally occurred 2 to 3 days after the increase in pore pressure, and the piezometric readings did not indicate any higher pressures, indicating that some other factor may have caused instantaneous pressure which was not recorded.

Such an event occurred on March 13 at a nearby mine where a large cast blast was being performed. Cast blasting includes the use of a large volume of explosive and heavy burden to cause the throw of material from the bench away from the coal such that excavation is reduced. Large vibrations were registered as a result of this blast at seismic monitoring centres in the province. This blast recorded a vibration equivalent to a 2+ on the Richter scale. Dynamic shock such as this imposed on the dump foundation in its near failure state could be responsible for causing strain induced pore pressure as the structure was subject to vibration. The vibration in turn causing sudden and/or cyclic loading of the soils.

Back analysis of the failure concluded the undrained shear strength (S_u) of the clay silt foundation soils was approximately 61 kPa.



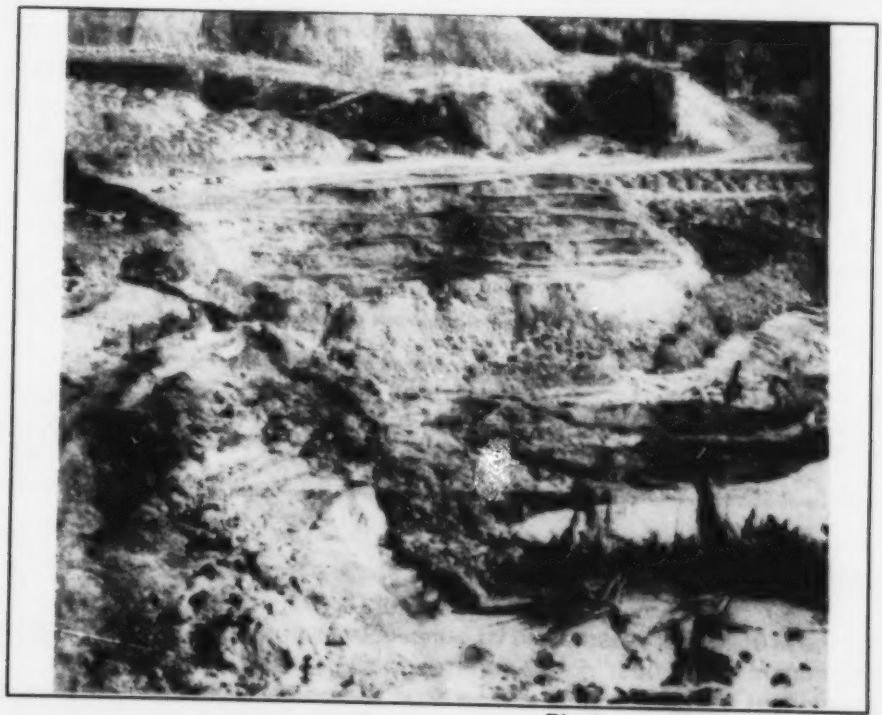


Photo credit: C.O. Brawner

Photograph 1: Record 39 dump failure.

MINE DUMP FAILURE SUMMARY

RECORD NO. 40

MINE: F - Open pit coal
DUMP NAME: F - Active at time of failure.
DATE OF FAILURE: May 5, 1990
DUMP HEIGHT: 25 m
FAILURE VOLUME: 1.5×10^6 m^3 (dump); 900,000 m^3 (foundation)
RUNOUT DIST.: 600 m

GENERAL DATA:

Topography Gently sloping floodplain of large river, average slope 2.5°-3.5°.
Geometry Benched, lift construction, linear in plan.
Foundation Fluvial sand and gravel overlying thick normally consolidated lacustrine clay-silt. Thin (2-20 mm) sand layers within clay-silt.
Construction 15 m benches, 5 m construction lifts dumped over crest or on platform and levelled by dozer.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests. Approximately 20% of dump material was overburden soil placed by contractor.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH ϕ'(°), c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >100mm	<#200
SANDSTONE (50)	>103	37°, 0	HIGH - V HIGH	75	5
SILTSTONE (20)	83		MED - HIGH	60	15
MUDSTONE (30)	7-34		V LOW - LOW	40	20

DESIGN ASSUMPTIONS:

Material Strengths Dump ϕ'=37°, c'=0; Foundation ϕ'=33°, c'=0; sand + gravel ϕ' = 30°, silt S_u = 60-250 kPa
Piezometric Assumptions Undrained shear strength.
Method of Stability Calculation Sarma - circular and translational.
Design Safety Factor 1.3 (static).

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
>50 m = 0	1-50Mm^3 = 50	26° = 0	<10° = 0	50	200
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
100	0	200	100	50	750/1800

FAILURE DETAILS:

Loading rate Loading rate varies across lift areas, a total of 17,000 m^3/day were placed over the failed area prior to failure.
Monitoring Pore pressure monitoring by piezometer, limit of 10 kPa/24 hour response, no significant changes since March 1990 failure in same area.
Climate Data Spring meltwater contributing to groundwater recharge and increased foundation seepage pressure.
Indicated Mode Horizontal translation along sand parting layer.
Indicated Cause Liquefaction within sand layers due to strain generated pore pressure; groundwater recharge.

DISCUSSION

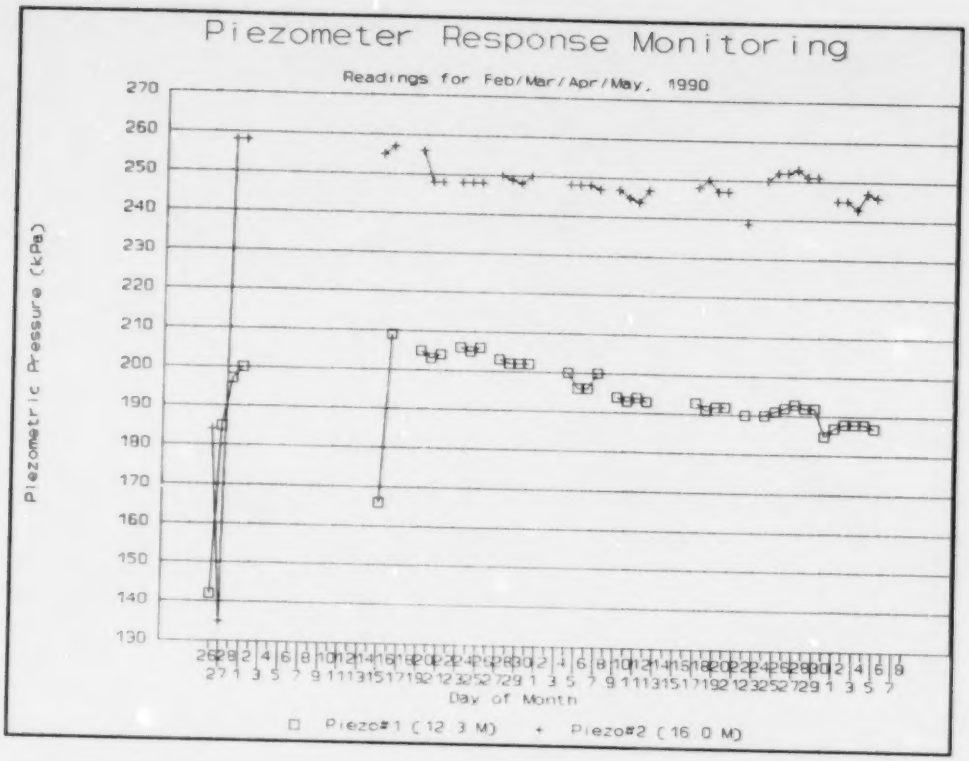
The low level benched dump was constructed on poor foundation conditions consisting of lacustrine clay silt and sand partings. The clay silt was recognized as being weak and susceptible to pore pressure generation upon loading. The dump was to be constructed in 5 m construction lifts creating a bench or lift up to 15 m high, piezometric pressures were to be monitored during construction.

Piezometer pressures were monitored during construction, and very little response was observed in the pore pressure since the March 1990 failure. Groundwater recharge of the natural soil, especially the sand partings which act as a conduit through the less permeable clay silt, was observed prior to the March event, although it was not directly responsible for the failure at that time. In a similar manner, this much larger failure mass was probably near failure for some time, and a catalyst resulting in sudden pore pressure response caused the failure. In this case a reasonable explanation is strain induced pore pressure within the sand partings. It is reasonable to conclude that the sand parting conduits will be influenced the most and carry the most pressure due to groundwater recharge. The sand partings may also be the most susceptible to strain induced pore pressure, being the most likely mechanism for failure.

As the dump and foundation is deformed under load, minute shearing within the natural soils causes the particles to compact, forcing the load to be carried by the water contained within the particle voids, resulting in an increase in pore pressure. The increase in pore pressure in a local area may be sufficient to cause liquefaction of the sand there and the resultant failure by translation of the mass above. As that mass is suddenly mobilized it loads adjacent areas rapidly, causing the mechanism to be repeated over a vast area.

Proof of this mechanism is offered by the observation of sand boils on the surface of the debris. The sand was carried to surface by water escaping in the form of springs from the confined layer and deposited as the water drained away.

The failure mass translated and blocked a major river for approximately 11 hours before a new channel was cut by the flow. Fine grained debris was carried away over time, while sand and small gravel size particles were deposited downstream in the form of sand bars. Large boulders of mine rock remain in the affected part of the river.


Piezometer Response Monitoring
Readings for Feb/Mar/Apr/May, 1990
Piezometric Pressure (kPa)
270
260
250
240
230
220
210
200
190
180
170
160
150
140
130
Day of Month
Piezo#1 (12.3 M)
Piezo#2 (16.0 M)

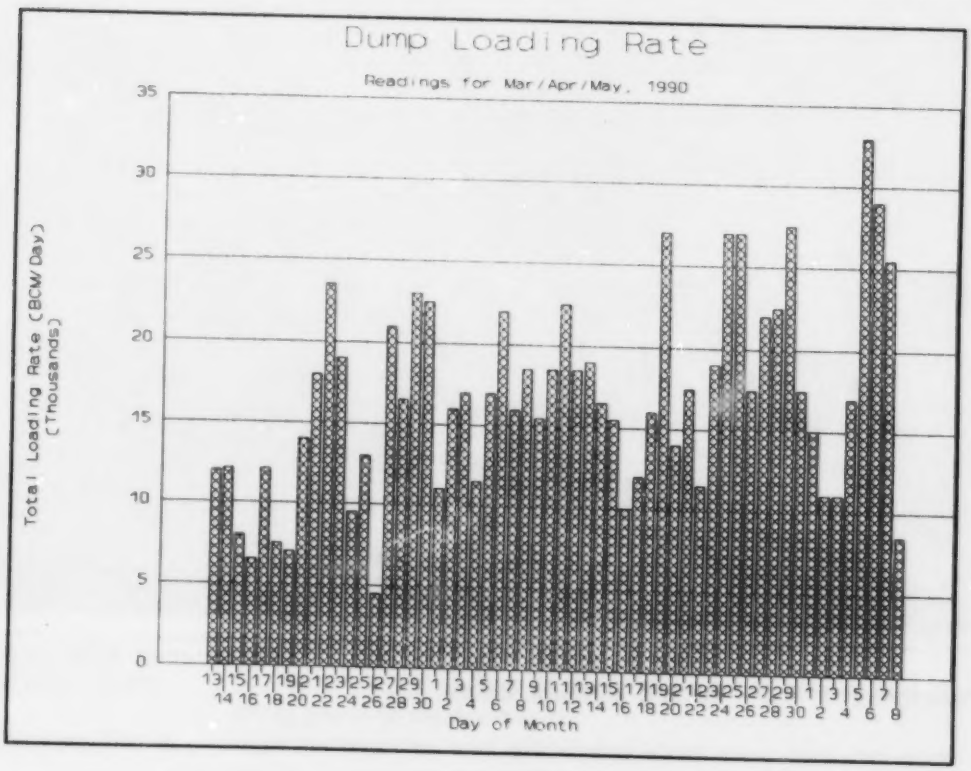

Dump Loading Rate
Readings for Mar/Apr/May, 1990
Total Loading Rate (BCM/Day)
(Thousands)
35
30
25
20
15
10
5
0
Day of Month

Photo credit: KPA Engineering

Photograph 1: Record 40 dump failure.

MINE DUMP FAILURE SUMMARY — RECORD NO. 41

MINE: F - Open pit coal
DUMP NAME: G - Active at time of failure.
DATE OF FAILURE: May 27, 1983
DUMP HEIGHT: 200 m (crest at elev. 1660 m, toe at elev. 1460 m)
FAILURE VOLUME: 100,000 m^3
RUNOUT DIST.: 350 m

GENERAL DATA:

Topography Toe slope = 11°-18°; mid slope = 28°; slope levels off above elevation 1575 m.

Geometry Unconfined sidehill fill, no 3D wedging effect.

Foundation Veneer of coarse free draining sandy gravel colluvium overlying folded sedimentary bedrock.

Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH $\phi'(^\circ)$, C'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >100mm	PARTICLE SIZE (%) <#200
SANDSTONE (50)	>103	37°,0	HIGH - V HIGH	75	5
SILTSTONE (20)	83		MED - HIGH	60	15
MUDSTONE (30)	7-34		V LOW - LOW	40	20

DESIGN ASSUMPTIONS:

Material Strengths Dump $\phi'=37°$, $c'=0$; Foundation $\phi'=33°$, $c'=0$

Piezometric Assumptions Drained (see legend)

Method of Stability Calculation Janbu

Design Safety Factor ~ 1.0 (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
100-200m = 100	1->50 Mm^3 = 50	37° = 100	25-32° = 100	100	100
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
200	200	200	300	0	1350/1800

FAILURE DETAILS:

Loading rate Loading rate not reported but considered a primary cause of instability.

Monitoring Visual record of crest deformation and face bulges reported in detail on following page.

Climate Data Snow contained in dump from construction in previous winter, melting of surface snow causing infiltration and seepage pressure may have promoted the melting of contained snow.

Indicated Mode Toe failure causing loss of support for mass above and planar sliding along plane of weakness.

Indicated Cause High loading rate and associated strain rate; captured snow forming a continuous plane of weakness; spring meltwater causing infiltration and groundwater recharge; redistribution of stresses.

DISCUSSION

The dump consisted of very poor quality material including fine grained carbonaceous mudstone and waste coal. Construction during winter months captured snow and effectively insulated it until rainwater or surface meltwater infiltration caused it to thaw. The snow formed a continuous plane of weakness on the winter construction slope, parallel to the face. The foundation topography was steepest in the area of the failure.

The failure was preceded by a period of intense deformation. Initially tension cracks were observed 10 m behind the crest, later the platform developed a graben approximately 5 m wide and up to 2 m in depth. This was accompanied by the development of a large bulge on the face about 1/3 down the slope. On May 25 the bulge section failed, coincident with the crest dropping by several metres below the old graben floor.

The high loading rate and associated strain observed in the dump indicated the development of failure planes within the material. In this case the principle failure plane was probably along the winter construction face, parallel to the original dump face. It appears from the record that little deformation of the toe was observed, such that a redistribution of stress within the dump (concurrent with platform and face bulge deformations) would result in the rapid loading of foundation soils at the stationary toe. As this loading continued the stresses within the toe material would become critical and fail, often in an explosive-like manner, causing a rapid loss of support for the material above. In this case, the material above failed along a plane of weakness identified by the winter construction.

MINE DUMP FAILURE SUMMARY — RECORD NO. 42

MINE: F - Open pit coal
DUMP NAME: G - Active at time of failure.
DATE OF FAILURE: November 7, 1987
DUMP HEIGHT: 255 m (crest at elev. 1660 m, toe at elev. 1405 m)
FAILURE VOLUME: 5.6×10^6 m^3
RUNOUT DIST.: 2000 m

GENERAL DATA:

Topography Toe slope = 11°-18°; mid slope = 28°; slope levels off above elev. 1575m.
Geometry Unconfined sidehill fill, no 3D wedging effect.
Foundation Veneer of coarse free draining sandy gravel colluvium overlying folded sedimentary bedrock.
Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH $\phi'(^\circ)$, c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >100mm	PARTICLE SIZE (%) <#200
SANDSTONE (50)	>103	37°, 0	HIGH - V.HIGH	75	5
SILTSTONE (20)	83		MED - HIGH	60	15
MUDSTONE (30)	7-34		V.LOW - LOW	40	20

DESIGN ASSUMPTIONS:

Material Strengths Dump $\phi'=37°$, $c'=0$; Foundation $\phi'=33°$, $c'=0$
Piezometric Assumptions Drained (see legend)
Method of Stability Calculation Janbu, Double Wedge
Design Safety Factor 1.47 (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
>200 m = 200	1-50 Mm^3 = 50	37° = 100	10 -25° = 50	100	100
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
200	200	200	200	0	**1400**/1800

FAILURE DETAILS:

Loading rate Peak loading rate of 500-600 BCM/m/day prior to failure.
Monitoring Average displacement rate of 0.5 m/day prior to failure.
Climate Data Precipitation of 18 mm rain October 28 to November 3 adding moisture to fines and elevating dump pore pressure.
Indicated Mode Toe failure along foundation contact causing loss of support and rotational slump through dump material.
Indicated Cause Loading rate causing increased pore pressure generation in foundation material; reduced shear strength of dump material due to elevated phreatic surface; water disposal from mine facilities.

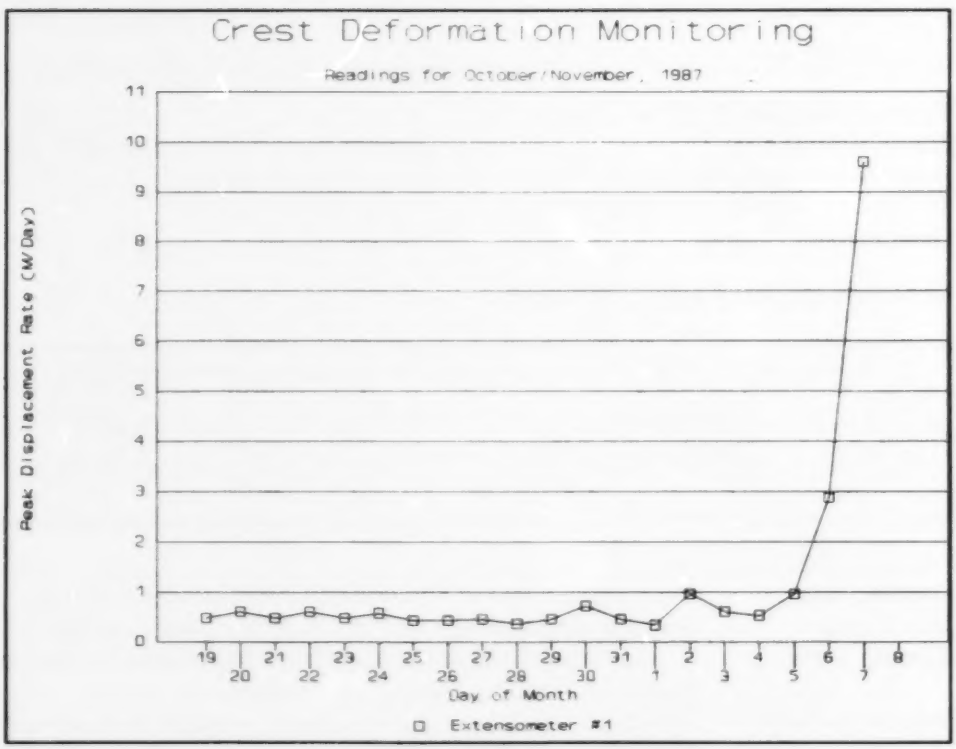
DISCUSSION

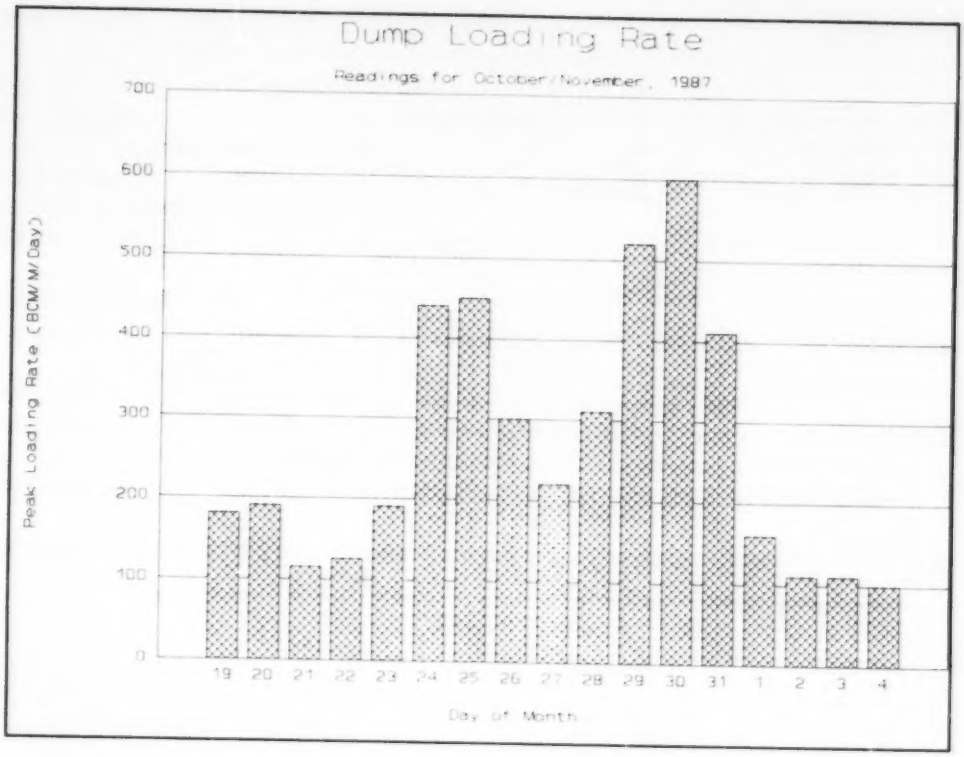
The dump consisted of a high percentage of fine grained material and low durability carbonaceous mudstone. Rapid loading of the dump did not produce the expected large strain or deformation which usually results. The dump toe was advancing over debris and disturbed natural soils from previous failure events.

Water discharge from the nearby plant was allowed to drain into the dump, however it is estimated that this discharge was much less than the dump capacity for drainage and should not have caused a stability problem. A drill hole collared at the platform was later used to investigate the dump, especially at the foundation contact. The driller reported losing circulation for the last 3.7 m, possibly indicating that the contact zone was free draining between coarse mine rock.

The failure was characterized by a 640 m long failure scarp, approximately 85 m back from the original crest. The failure plane involved shearing at or slightly below the foundation contact and through the dump material itself.

Toe failure likely initiated at the foundation toe area due to the high rate of loading, the resulting loss of support for the mass above caused the dump to fail in a rotational manner, along sections of the foundation contact at lower elevations and through the dump material itself above this elevation.




Dump Loading Rate
Readings for October/November, 1987
Peak Loading Rate (BCM/M/Day)
700
600
500
400
300
200
100
0
19 20 21 22 23 24 25 26 27 28 29 30 31 1 2 3 4
Day of Month

MINE DUMP FAILURE SUMMARY — RECORD NO. 43

MINE: F- Open pit coal
DUMP NAME: H - Active at time of failure.
DATE OF FAILURE: May 12, 1988
DUMP HEIGHT: 200 m (crest at elev. 1675 m, toe at elev. 1475 m)
FAILURE VOLUME: 80,000 m^3
RUNOUT DIST.: 800 m (average slope 10°)

GENERAL DATA:

Topography Toe slope = 32°; mid slope = 38°; crest slope = 44°; concave downward in profile.

Geometry Unconfined sidehill fill, no 3D wedging effect.

Foundation Veneer of coarse free draining sandy gravel colluvium overlying folded sedimentary bedrock. Bedrock is exposed at many locations.

Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH ϕ'(), c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >100mm	PARTICLE SIZE (%) <#200
SANDSTONE (50)	>103	37°, 0	HIGH - V HIGH	75	5
SILTSTONE (20)	83		MED - HIGH	60	15
MUDSTONE (30)	7-34		V LOW - LOW	40	20

DESIGN ASSUMPTIONS:

Material Strengths Dump ϕ'=37°, c'=0; Foundation ϕ'=33°, c'=0

Piezometric Assumptions Drained (see legend)

Method of Stability Calculation Janbu

Design Safety Factor ~ 1.0, (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
100 - 200 m = 200	MED = 50	37° = 100	<32° = 200	100	200
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
200	200	100	200	0	1550/1800

FAILURE DETAILS:

Loading rate Loading rate considered a primary factor of instability.

Monitoring Crest deformation abruptly accelerated to 21 cm/h prior to failure, the operating limit was 5 cm/h.

Climate Data Intense spring melt between May 8-14 contributing to groundwater recharge and surface infiltration.

Indicated Mode Toe failure causing loss of support for mass above and failure along a plane of weakness.

Indicated Cause High percentage of fine grained material causing oversteeping; lack of toe support; spring melt adding to material moisture content and foundation seepage pressures.

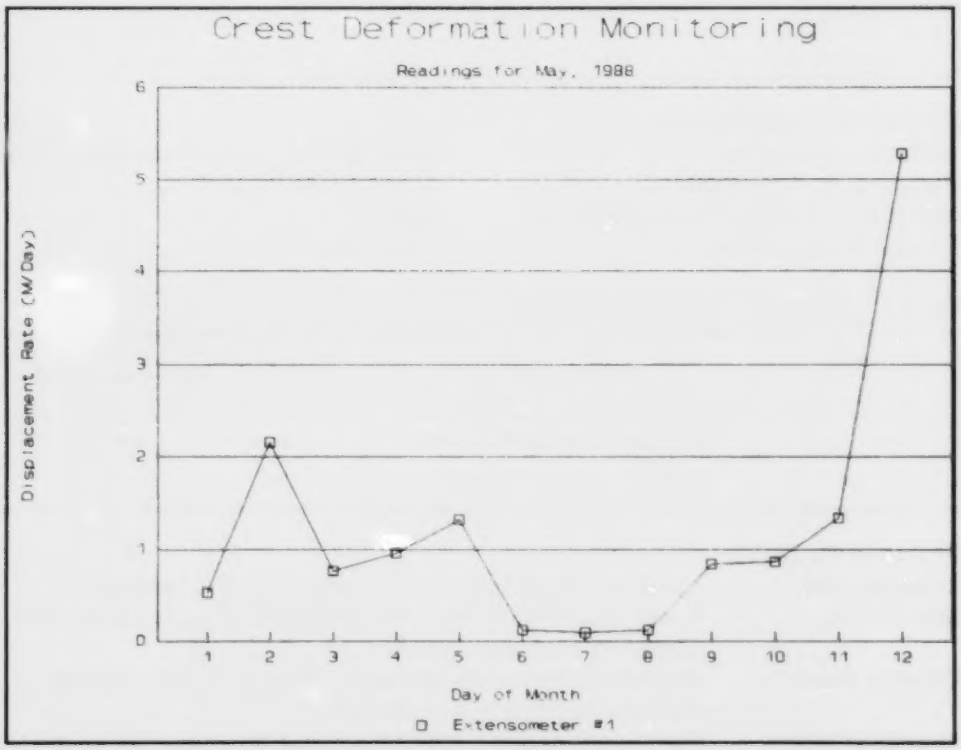
DISCUSSION

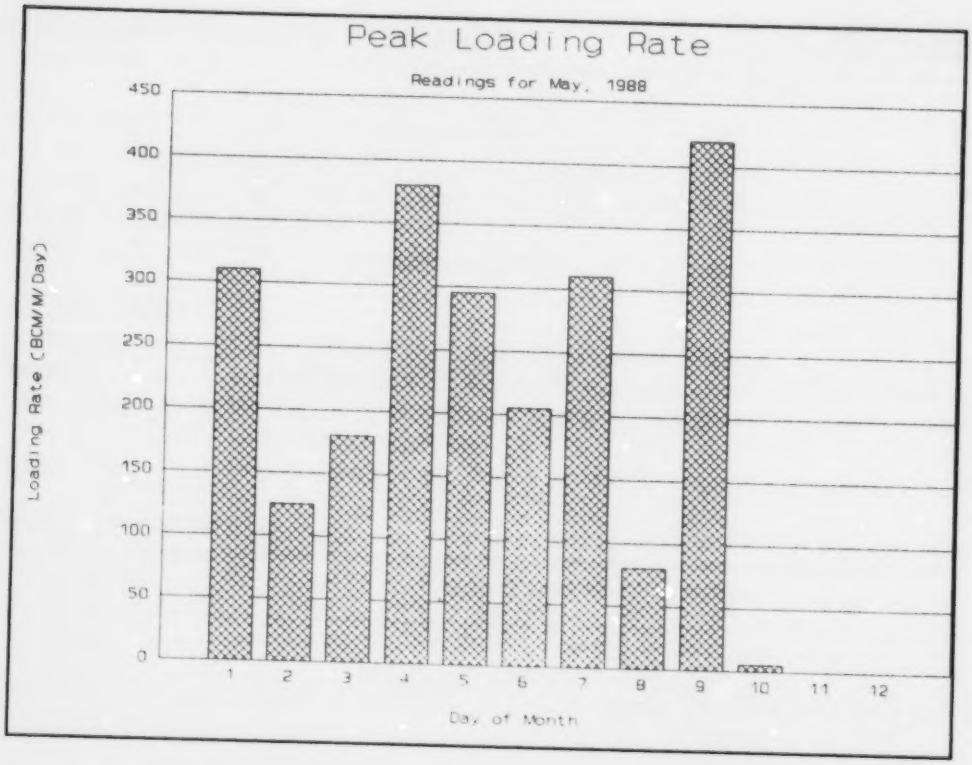
The dump consists of fine grained material and low durability carbonaceous mudstone. The dump geometry was very poor, and had reached the most critical stage of development: maximum height, minimum toe support. In this location the dump was also susceptible to seepage pressures due to stream flow along valley axis.

Visual observations made prior to failure indicate a period of intense deformation including the development of crest bulge oversteepened to 42°, approximately 65 m downslope. Inspection of the crest bulge identified the presence of an underlying thickness of 2-3 m fine grained material, which the bulge appeared to be moving along.

Oversteepening of the dump crest due to fines and the development of a bulge increased the toe load, while the toe appeared to be stable at the time, spring discharge was observed to suddenly appear approximately 1 hour prior to failure. This is consistent with increased pore pressure due to higher loads.

Toe failure occurred when the foundation pore pressure generation exceeded the capacity for dissipation causing a reduction in shear strength. The loss of support caused an unstable condition for the mass above resulting in failure along a plane of weakness, in this case a shallow failure plane resembling a sliver failure. The debris moved rapidly and fluid-like although it appeared to be dry after the failure. A large percentage of fines were observed in the debris.




Peak Loading Rate
Readings for May, 1988
Loading Rate (BCM/M/Day)
450
400
350
300
250
200
150
100
50
0
1
2
3
4
5
6
7
8
9
10
11
12
Day of Month

MINE DUMP FAILURE SUMMARY — RECORD NO. 44

MINE: F- Open pit coal
DUMP NAME: I - Active at time of failure.
DATE OF FAILURE: June 30, 1986
DUMP HEIGHT: 180 m (crest at elev. 1705 m, toe at elev. 1525 m)
FAILURE VOLUME: 1.2×10^6 m^3
RUNOUT DIST.: 1700 m (average slope 5-9°)

GENERAL DATA:

Topography Toe = 16-37°; mid slope = 22°; crest slope 22°-0°.
Geometry Unconfined sidehill fill, no 3D wedging effect, convex shape in plan.
Foundation Veneer of coarse free draining sandy gravel colluvium overlying folded sedimentary bedrock.
Construction End dumped or pushed directly over crest in a single lift.

MATERIAL PROPERTIES: Values are estimated or based on an average of laboratory tests.

DUMP ROCK TYPE (% BY VOLUME)	UCS (MPa)	ESTIMATED STRENGTH $\phi'(^\circ)$, c'(kPa)	DURABILITY (%)	PARTICLE SIZE (%) >100mm	PARTICLE SIZE (%) <#200
SANDSTONE (50)	>103	37°, 0	HIGH - V.HIGH	75	5
SILTSTONE (20)	83		MED - HIGH	60	15
MUDSTONE (30)	7-34		V.LOW - LOW	40	20

DESIGN ASSUMPTIONS:

Material Strengths Dump $\phi'=37°$, $c'=0$; Foundation $\phi'=33°$, $c'=0$
Piezometric Assumptions Drained (see legend)
Method of Stability Calculation Janbu, Double Wedge
Design Safety Factor ~1.2 (static)

DUMP STABILITY RATING SCHEME:

HEIGHT	VOLUME	DUMP SLOPE	FOUNDATION SLOPE	CONFINEMENT	FOUNDATION TYPE
100-200 m = 100	1-50 Mm^3 = 50	37° = 100	25-32° = 100	100	100
MATERIAL QUALITY	CONSTRUCTION	PIEZOMETRIC/CLIMATE	DUMP RATE	SEISMICITY	DUMP RATING
200	200	200	200	0	1350/1800

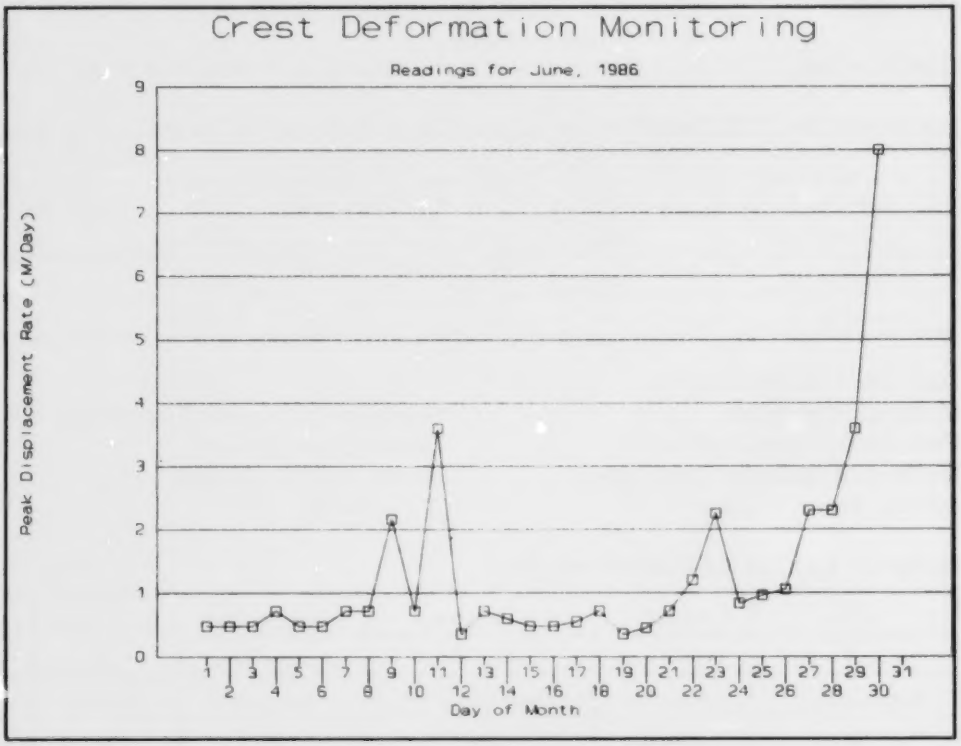
FAILURE DETAILS:

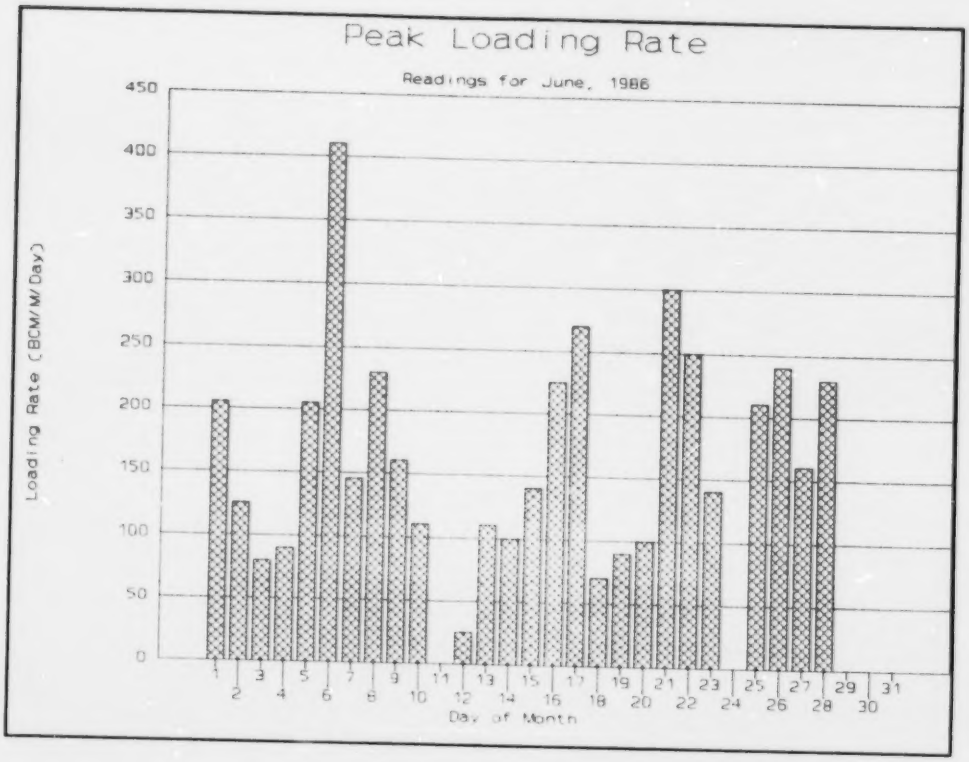
Loading rate The average loading rate for the dump was 136 BCM/m/day. Peak loading rates of 200 BCM/m/day were placed prior to failure.
Monitoring Large strains were observed on the dump platform with readings 30 cm/h prior to failure.
Climate Data Heavy rain and infiltration into dump prior to failure.
Indicated Mode Rotational, through dump material.
Indicated Cause Pore pressure within dump material caused by infiltration; steep foundation slopes; redistribution of stresses; history of high deformation and slides in previous year.

DISCUSSION

The dump consisted generally of good to fair quality material, mostly durable sandstone and conglomerate. The dump geometry was poor, with relatively steep foundation slopes and lack of confinement due to the convex shape. The dump had a history of high deformations related to precipitation which may indicate the presence of captured snow forming a plane of weakness within the dump, although this was not reported.

The failure was characterized by a backscarp 40-50 m behind the original crest, and observations by eye witnesses who reported that the toe "exploded" into the valley, causing a loss of support for the mass above. The debris appeared to flow like water and travelled at a velocity of 70-90 km/h.




Peak Loading Rate
Readings for June, 1986
Loading Rate (BCM/M/Day)
450
400
350
300
250
200
150
100
50
0
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
Day of Month

APPENDIX B
Mine Dump Stability Rating Scheme (MEMPR, 1991a)

DUMP STABILITY RATING SCHEME

KEY FACTORS AFFECTING STABILITY	RANGE OF CONDITIONS OR DESCRIPTION		POINT RATING
DUMP CONFIGURATION			
DUMP HEIGHT		< 50m	0
		50m - 100m	50
		100m - 200m	100
		> 200m	200
DUMP VOLUME	Small	< 1 million BCM's	0
	Medium	1 - 50 million BCM's	50
	Large	> 50 million BCM's	100
DUMP SLOPE	Flat	< 26°	0
	Moderate	26° - 35°	50
	Steep	> 35°	100
FOUNDATION SLOPE	Flat	< 10°	0
	Moderate	10° - 25°	50
	Steep	25° - 32°	100
	Extreme	> 32°	200
DEGREE OF CONFINEMENT	Confined	-Concave slope in plan or section -Valley or Cross-Valley fill, toe butressed against opposite valley wall -Incised gullies which can be used to limit foundation slope during development	0
	Moderately Confined	-Natural benches or terraces on slope -Even slopes, limited natural topographic diversity -Heaped, Sidehill or broad Valley or Cross-Valley fills	50
	Unconfined	-Convex slope in plan or section -Sidehill or Ridge Crest fill with no toe confinement -No gullies or benches to assist development	100
FOUNDATION TYPE	Competent	-Foundation materials as strong or stronger than dump materials -Not subject to adverse pore pressures -No adverse geologic structure	0
	Intermediate	-Intermediate between competent and weak -Soils gain strength with consolidation -Adverse pore pressures dissipate if loading rate controlled	100
	Weak	-Limited bearing capacity, soft soils -Subject to adverse pore pressure generation upon loading -Adverse groundwater conditions, springs or seeps -Strength sensitive to shear strain, potentially liquefiable	200
DUMP MATERIAL QUALITY	High	-Strong, durable -Less than about 10% fines	0
	Moderate	-Moderately strong, variable durability -10 to 25% fines	100
	Poor	-Predominantly weak rocks of low durability -Greater than about 25% fines, overburden	200

Continued..

KEY FACTORS AFFECTING STABILITY	RANGE OF CONDITIONS OR DESCRIPTION		POINT RATING
METHOD OF CONSTRUCTION	Favourable	-Thin lifts (<25m thick), wide platforms -Dumping along contours -Ascending construction -Wrap-arounds or terraces	0
	Mixed	-Moderately thick lifts (25m - 50m) -Mixed construction methods	100
	Unfavourable	-Thick lifts (> 50m), narrow platform (sliver fill) -Dumping down the fall line of the slope -Descending construction	200
PIEZOMETRIC AND CLIMATIC CONDITIONS	Favourable	-Low piezometric pressures, no seepage in foundation -Development of phreatic surface within dump unlikely -Limited precipitation -Minimal infiltration into dump -No snow or ice layers in dump or foundation	0
	Intermediate	-Moderate piezometric pressures, some seeps in foundation -Limited development of phreatic surface in dump possible -Moderate precipitation -High infiltration into dump -Discontinuous snow or ice lenses or layers in dump	100
	Unfavourable	-High piezometric pressures, springs in foundation -High precipitation -Significant potential for development of phreatic surface or perched water tables in dump -Continuous layers or lenses of snow or ice in dump or foundation	200
DUMPING RATE	Slow	-< 25 BCM's per lineal metre of crest per day -Crest advancement rate < 0.1m per day	0
	Moderate	-25 - 200 BCM's per lineal metre of crest per day -Crest advancement rate 0.1m - 1.0m per day	100
	High	-> 200 BCM's per lineal metre of crest per day -Crest advancement > 1.0m per day	200
SEISMICITY	Low	Seismic Risk Zones 0 and 1	0
	Moderate	Seismic Risk Zones 2 and 3	50
	High	Seismic Risk Zones 4 or higher	100

MAXIMUM POSSIBLE DUMP STABILITY RATING: **1800**